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FINAL REPORT

Contract No. FA64WA-5025

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FLIGHT CALIBRATION OF AIRCRAFT STATIC PRESSURE SYSTEMS

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Systems Research & Development Service

by

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Minneapolis, Minnesota 55435

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ADDENDUM

SRDS Report No. RD-66-3

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FLIGHT CALIBRATION OF AIRCRAFT
STATIC PRESSURE SYSTEMS

February 1966

Page 7.8, Line 9: Add the following sentence: This test should be conducted with the trailing cone assembly under at least 100 pounds tension applied so as to simulate flight loading.

Page 7.12: Add the following sentence: (8) The leak testing specified in Section 7.3.1 (5) should be repeated after the flight test.

Page 7.13: Add the following sentence: E 3) Repeat leak check.

Issued October 20, 1966

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FLIGHT CALIBRATION OF AIRCRAFT STATIC PRESSURE SYSTEMS

February 1966

Prepared by
Richard V. DeLeo
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ABSTRACT

This report describes four methods of static pressure flight calibration: (1) Camera Fly-Over or Tower Fly-By, (2) Pacer Aircraft, (3) Radar Tracking, and (4) Trailing Probe. The equipment required for each method is listed as well as the accuracy expected and the personnel and flight time required. Complete pre-flight, in-flight, and post-flight procedures and detailed data reduction procedures are described for each method. Data formats are included, as well as suggestions for final data analysis and presentation in correction card form. General background information on the standard atmosphere, altimeters, altimeter errors, and static pressure system errors are included.

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SECTION I

INTRODUCTION

Measurements of aircraft altitude are required for maintaining vertical separation between aircraft during flight. In recent years, witn increasing speed and altitude of aircraft, the maintenance of accuracy of pressure-altitude measuring systems has become more difficult. Accurate calibrations of aircraft altimeter systems are needed to insure safety during flight. Altimeter system errors are commonly broken down into flight technical errors, instrument errors, and static pressure errors.

Static pressure error may be defined as a difference between local pressure at the static pressure port of an aircraft and the true atmospheric pressure. It is often called the position error. The magnitude of the position error is dependent primarily on the following variables:

(1.) Location of the static port on the aircraft.
(2.) Physical condition of the static ports.
(3.) Aircraft velocity and Mach number.
(4.) Angle of attack of the aircraft.
(5.) Aircraft configuration.
(6.) Angle of sideslip of the aircraft.

Methods of determining position error are described in detail in this report.

Altimeter instrument error may be defined as an error in reading or indication due solely to the limitations of the pressure sensitive instrument. Although the subject of altimeter instrument errors is not considered in detail in this report, a general listing and definitions of instrument errors are included in Section 2. The subject of flight technical error, not considered in this report, may be defined as inability of the pilot or auto pilot to hold a prescribed altitude. Flight technical error includes error introduced by reported altimeter setting.

This report is divided into several sections. Four methods of static pressure flight calibration are first briefly described (Section 3) to provide the reader with a basis for a choice of method. The equipment required is listed as well as the accuracy expected and the personnel and flight time required. Each method for in-flight calibration is then described in detail in separate sections. These sections include a complete detailed listing of the equipment needed as well as pre-flight and in-flight procedures. In a separate section, detailed data reduction procedures are described for each method. Data formats are included, as well as suggestions for final data analysis and presentation in correction card form. General background information on the standard atmosphere, altimeters, and altimeter errors, and static pressure system errors are included in Section 2. A knowledge of this section is not necessary to perform the detailed calibration procedures described in Sections 4 through 7 of the report.

SECTION 2

THEORY AND PROBLEMS OF PRESSURE ALTITUDE MEASUREMENTS

(Persons interested in procedures only can omit this section and go directly to Section 3)

2.1 THE STANDARD ATMOSPHERE

The gaseous atmosphere layer surrounding the Earth exerts a pressure on all surfaces which it contacts. This pressure varies with altitude or height exactly as the pressure in a liquid varies with depth. The atmospheric pressure is greatest near the Earth and decreases as distance or altitude from the Earth surface increases.

A standard atmosphere represents a standard variation of atmosphere air pressure with altitude. Most aircraft altimeters are absolute pressure gages calibrated to read in terms of feet of altitude using the standard atmosphere relationship. A standard atmosphere may be calculated if standard values and variation of gas properties and gravitational acceleration are selected. The hydro-static differential equation, (1), is assumed valid in the Earth's Atmosphere. It may be integrated by substituting the perfect gas equation, (2), into either of the forms shown as equations (3) and (4).

$$dP = -\rho g dZ \qquad (1)$$

dP = pressure difference
dZ = height difference
ρ = density
g = acceleration due to Earth's gravitation.

$$\rho = P/RT \qquad (2)$$

P = static pressure
R = gas constant
T = temperature.

$$\int_{P_o}^{P} \frac{dP}{P} = -\frac{g_o}{R} \int_{0}^{Z} \frac{dZ}{T} \tag{3}$$

P_o = standard sea level value of static pressure,
g_o = standard sea level value of acceleration due to gravity,
Z = geometric altitude,
T = static temperature, depends on altitude.

$$\int_{P_o}^{P} \frac{dP}{P} = -\frac{1}{R} \int_{0}^{Z} \frac{g\,dZ}{T} \tag{4}$$

g = gravitation acceleration, depends on altitude.

$$H = \int_{0}^{Z} \frac{g\,dZ}{g_o} = \frac{1}{g_o} \int_{0}^{Z} g\,dZ \tag{5}$$

H = geopotential altitude, feet.

The solution shown in integral form, in Equation 3, is one where the acceleration due to the Earth's gravitation is assumed constant. Early standard atmospheres were derived using this expression, References 1 through 3. An alternate form is shown in Equation 4, where g is actually a function of the geometric altitude, Z. The mathematical relationship between the geometric altitude, Z, and the geopotential altitude, H, is given by Equation (5). One standard geopotential foot is the vertical distance through which one pound mass must be lifted against the force of gravity to increase its potential energy by one foot pound. Newer standard atmospheres, References 6 to 9, are all basically geopotential standard atmospheres. The atmospheres for References 5, 6, and 9 give the pressure altitude relationship in terms of geopotential altitude. Standard atmospheres of References 7, 8, and 13, give the pressure altitude relationship in terms of both geopotential and geometric altitude Z. The newer geopotential standard atmosphere offers

the advantage that a standard atmosphere tabulated in geopotential units will provide greater geometric altitude separation. For example, the 70,000 - 60,000 ft geopotential height difference provides a geometric difference of 10,063 feet. A standard atmosphere calculated from Equation (4) would be exactly correct in geometric units, but would have the effect of decreasing altitude separations.

Since 1925 there have been only two basic standard atmospheres in use in the United States. They are listed in two groups as follows:

Group I: Standard Atmospheres: Geometri asure calculated using constant gravitational acceleration.

One of the early standard atmospheres is given in NACA Report Number 218, published in 1925. It is a geometric standard atmosphere calculated on the assumption of constant gravity, equal to the value at sea level, from sea level to 65,000 feet. Values of pressure in 5,000 feet intervals are tabulated as part of Table I in Column I. Between 1925 and 1952 several other atmospheric tables were published, but these were identical. NACA Tech Note No. 538, published in 1935, extends the range of altitude to 80,000 feet. The purpose of NACA Report No. 837, published in 1946, was to extend the atmosphere to 100,000 feet. A common fault of the first three standard atmospheres is that over part of the range of altitude, pressures were arbitrarily rounded off to the nearest hundredth of an inch of mercury. The Kollsman Instrument Corporation established a Kollsman standard atmosphere which is identical to the other three except that more significant figures had been carried in the calculation.

Group II: Standard Atmospheres: Geopotential measure calculated using inverse square gravitational acceleration.

A later group of standard atmospheres have been tabulated, References 5 through 9. In all cases these are geopotential. The 1959 ARDC Standard Atmosphere, Reference 8, is not tabulated at even values of geopotential altitude; hence it is less convenient for altimeter calibration work.

TABLE I

COMPARISON OF VARIOUS STANDARD ATMOSPHERES

Z = Geometric Feet H = Geopotential Feet

Pressures Tabulated Are In Units Of Inches Of Mercury Absolute

Z or H	(1) NACA 218 1925 (Z)	(2) NACA 1235 1955 (H)	(3) ARDC 1956 (H)	(4) U.S. STD 1962 (H)
0	29.92	29.9213	29.921	29.9213
5000	24.89	24.8959	24.896	24.8959
10000	20.58	20.5769	20.577	20.5770
15000	16.88	16.8858	16.886	16.8858
20000	13.75	13.7501	13.750	13.7501
25000	11.10	11.1035	11.103	11.1035
30000	8.880	8.88541	8.8854	8.88544
35000	7.036	7.04060	7.0406	7.04062
40000	5.541	5.53801	5.5380	5.53802
45000	4.364	4.35497	4.3549	4.35498
50000	3.436	3.42466	3.4246	3.42466
55000	2.707	2.69308	2.6931	2.69308
60000	2.132	2.11778	2.1178	2.11778
65000	1.680	1.66538		1.66537
70000			1.3096	1.31046
75000				1.03290
80000			.80985	.815462
85000				.644846
90000			.50397	.510745
95000				.405172
100000			.31951	.321922

Three recent geopotential standard atmospheres may be compared up to 60,000 feet, directly from Table I. It is obvious that all three are identical to four significant figures. NACA 1235 standard atmosphere terminates at 65,000 feet. Partial tabulations of the two later standard atmospheres are shown to H = 100,000 feet, Table I. The actual published tabulations continue to higher levels.

In summary, standard atmospheres published in the United States within the last 35 years fall into two groups. One is a geometric standard atmosphere calculated using constant gravitational acceleration. The other is a geopotential atmosphere which accounts for variable gravity effects. Within each of these two groups comparison between different published standard atmospheres shows that they are identical for all practical purposes. The difference in standard atmosphere given by NACA Report 218, (Group I) and the ARDC 1956 standard atmosphere (Group II) in feet of altitude vs. altitude is shown graphically in Figure 2.1. Up to approximately 35,000 feet, differences are less than 15 feet. Between 35,000 and 60,000 feet of altitude, the difference steadily increases. At 60,000 feet, the altitude indicated by an altimeter calibrated per standard atmosphere "218" will read 139 feet low as compared to an altimeter calibrated to a standard atmosphere per "1956" geopotential atmosphere.

A comparison of two recent standard atmospheres also indicated in Figure 2.1 shows no significant difference between sea level and 60,000 feet. Difference increases above this altitude to 150 feet at 80,000 feet.

Recommendation: In order to insure consistency in static pressure calibrations, consistent standard atmospheres must be used for instrument calibration and conversion of pressure errors into equivalent feet of altitude. For calibrations below 60,000 feet of altitude, the geopotential standard atmosphere should be from either NACA Report 1235, 1955 (Ref. 6), 1956 ARDC Model Atmosphere (Ref. 7), or 1962 U.S. Standard Atmosphere (Ref. 13). Above 60,000 feet only 1962 U.S. Standard Atmosphere should be utilized.

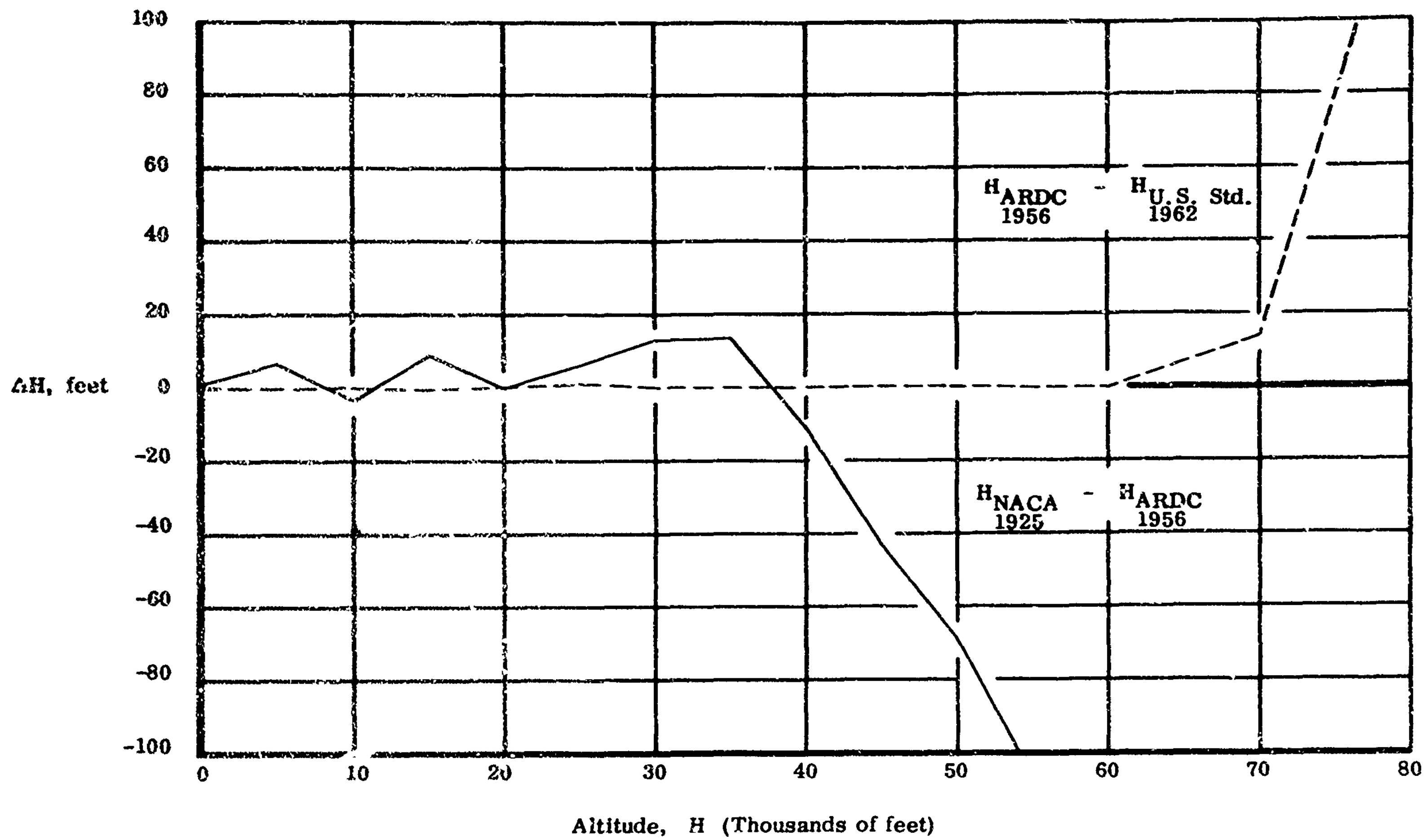


Figure 2.1

Pressure Altitude Difference for Three Standard Atmospheres

$$\Delta H = -\frac{\Delta P}{\rho}$$

2.2 ALTIMETERS AND ALTIMETER ERRORS

2.2.1 Types Of Full Range Altimeters

Most altitude measurements are made with mechanical type absolute pressure gages with scales to read in altitude units in agreement with the accepted Standard Atmosphere (see Section 2.1). When installed in aircraft, the altimeter is connected using air tight gas transmission lines to a suitable static pressure source. The altimeter in its simplest form is shown by the sketch of Figure 2.2(A). It consists of an evacuated diaphragm or capsule mounted in an air-tight case or static pressure chamber. The diaphragm responds to changes in pressure by expanding and contracting. The movement of the diaphragm is transmitted to a rocking shaft assembly and then to a main pinion assembly. The schematic of Figure 2.2(A) shows simple coupling between rocking shaft, pinion, and pointer. Movement magnification can be produced by additional pinion combinations. The simple mechanism shown as Figure 2.2(A) is typical of the "sensitive" altimeter movement used for altimeters in the 0 - 35,000 foot and 0 - 50,000 foot range. Since the pressures at higher altitudes are relatively small, two diaphragms have been used in the "precision" altimeter movement as shown in Figure 2.2(B). An additional advantage of the dual diaphragm construction is reduced diaphragm stresses for a given deflection. This construction has been used for altimeters in the 0- 80,000 foot range.

Most altimeters have three concentrically arranged pointers. They indicate on a common scale in units of one hundred, one thousand, and ten thousand feet, respectively. In moving over a range of 80,000 feet, the longest pointer makes eighty revolutions, the intermediate pointer eight revolutions, and the smallest or inverted pointer (or disk with pointer) makes 0.8 revolutions. Other presentations are used such as "drum-pointer" type, shown on Figure 2.2(B), with indications in thousands of feet on a drum visible through a vertical window. In the "counter-pointer" type, a pointer indicates hundreds of feet making one revolution per thousand feet. Counter digits indicate thousands and tens of thousands of feet.

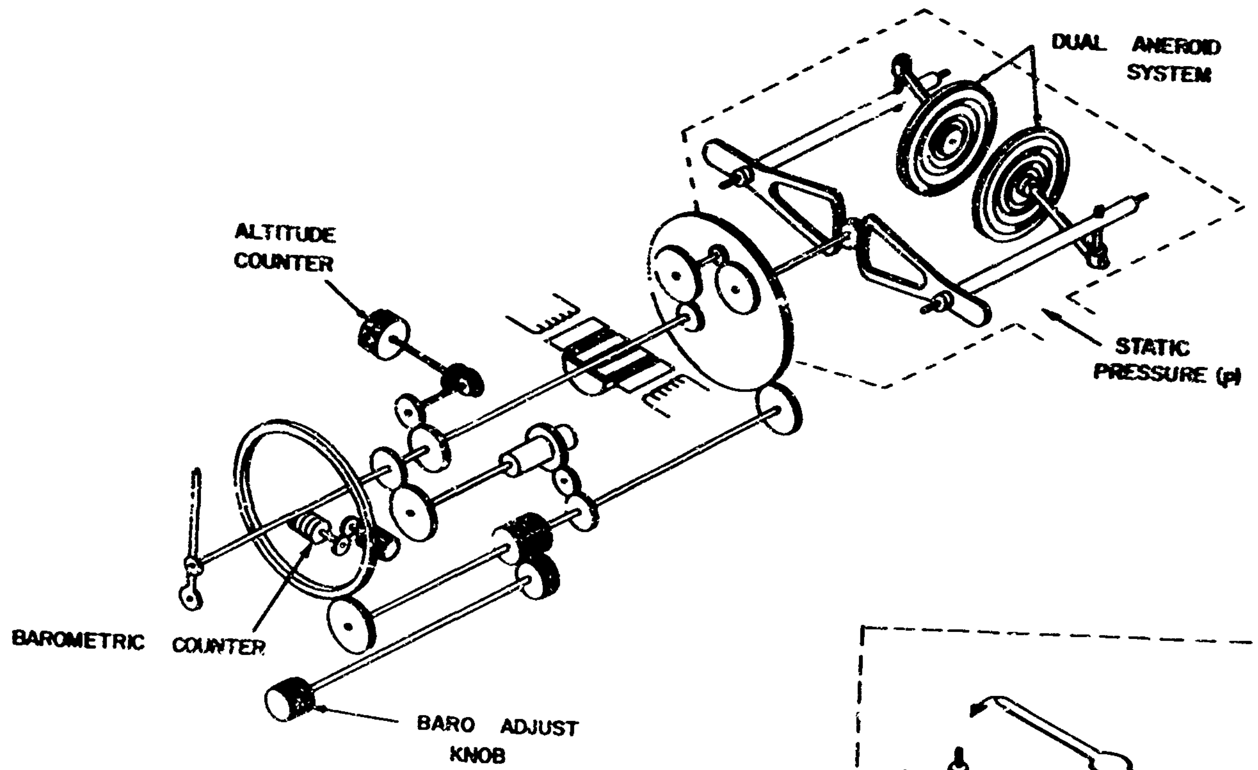


Figure 2.2B

Simplified Schemat.c of a Typical Precision Altimeter with Scale Error Correction

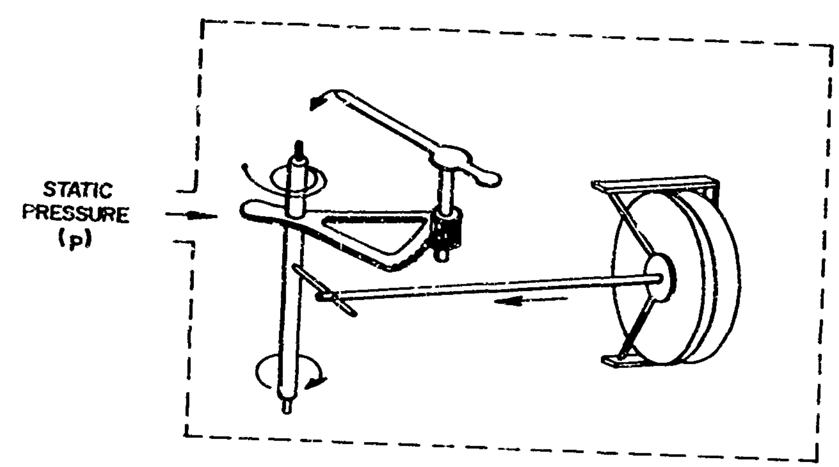


Fig ire 2.2A

Simplified Schematic of Sensitive Altimeter

Several other altimeters are in use. One is similar to that shown in Figure 2.2(B) and employs an electro-mechanical method for scale error correction. The scale or diaphragm errors of the mechanical altimeter are automatically corrected through the use of servos. The altimeter and diaphragm error corrector form a matched set.

Vertical tape presentations of altitude are common in military aircraft. These units are usually servo driven from an air data computer.

2.2.2 Altimeter Errors

(This section considers typical aircraft altimeter errors. For a complete discussion of "Altimetry Errors and Their Effect on Aircraft Operations" the reader is referred to Volume I, Manual of Barometry, First Edition, Reference 14).

Altimeter errors may be defined as the errors in reading due to mechanical, operational, and installation errors.

Mechanical errors are due to mechanical limitations of the instrument; operational errors are due to adjustments, mounting, scale factor and reading; and installation errors are due to systems leaks, pressure lag, and static pressure defect. These subdivisions are listed below and are in part those definitions as they appear in Reference 14.

(a) Mechanical Errors

1. Diaphragm Error (scale error) -- The error in the indication of an altimeter due to the physical properties and construction of the aneroid and linkage system, which results in a variable response in diaphragm deflection for equal changes in atmospheric pressure at different heights.

2. Hysteresis Error -- The error in the indication of an altimeter introduced during an increase or decrease in height, due to the imperfectly elastic properties of the aneroid material which prevent the aneroid from assuming its normal shape for a given atmospheric pressure.

3. <u>Drift Error</u> -- The error in the indication of an altimeter due to the recovery effect which will occur with time when the instrument is exposed to a certain pressure.

4. <u>Friction Error</u> -- The error in the indication given by an altimeter due to friction in the mechanism.

5. <u>Temperature Error</u> -- The error in the indication of an altimeter due to the effect of temperature variation on its mechanism.

6. <u>Backlash Error</u> -- The error in the indication of an altimeter due to lost motion in the gear transmission between the height scale and the pressure scale.

7. <u>Static Balance Error</u> -- The error in the indication of an altimeter due to changes in the state of static balance of the mechanism when it is rotated from the test position to other positions.

Note: This error is introduced when a pressure setting other than 29.92 inches of mercury (1013.25 mb.) is used, since it is caused by the rotation of the altimeter mechanism.

8. <u>Coordination Error</u> -- The error in the indication of an altimeter due to inability to obtain the correct relationship between the graduation of the pressure scale and the height scale.

Note: This error does not occur in the instruments having a fixed pressure datum.

9. <u>Instability Error</u> -- The change apparent in the indication of an altimeter following consecutive ascents and descents.

Note: This error, being additional to the errors numbered 1 to 8 inclusive, may occur any time after the original test of the instrument is completed and consequently is outside the limits specified in the tolerances for diaphragm and drift tests. It may be due to the variable behavior of the instrument

mechanism during the changes in pressure on different occasions and/or inaccuracies in the method of testing.

(b) Operation and Installation Errors

10. Zero-Setting Error -- The error in the indication of an altimeter due to the displacement of the reference pressure datum from that used during test (29.92 in. Hg, 1013.25 mb.) to some other pressure.

Note: The use of a setting other than 29.92 in. Hg (1013.25 mb.) has the effect of altering the diaphragm-plus-drift tolerance.

11. Readability Error -- The error due to parallax effects when reading the graduations on the height scale and the pressure scale.

12. Static Pressure System Error -- The error in the indication of an altimeter due to a static pressure source which applies to the instrument a pressure other than ambient atmospheric pressure.

13. Barometric Setting Error -- The error in indication of an altimeter due to the incorrect setting of the barometric pressure datum.

A listing of typical instrument errors as a function of altitude is presented as Table II. Errors are for a "precision" or double diaphragm type mechanism previously described. The values in parentheses under diaphragm and hysteresis and drift errors in Table II are the residual errors after scale error correction for a servo altimeter. These values in parentheses are also indicative of a calibrated precision altimeter corrected for scale error. The errors listed in Table II are the maximum values of component errors. The table is limited to instruments with altimeter setting constant at a standard value of 29.92 inches of mercury. For a variable setting, errors listed under (b) above, Operation and Installation Errors, must also be included.

TABLE II

ESTIMATED ALTITUDE MEASUREMENT ERRORS FOR TYPICAL PRECISION PRESSURE ALTIMETER (0-50,000 Ft Range)

Maximum Tolerances, Feet

Height x 1000 ft	0	5	10	15	20	25	30	35	40	45	50	60	70	80	90	100
1. Diaphragm* +																
2. Hysteresis +		55	80	105	130	155	180	205	230	255	280					
3. Drift		(20)	(30)	(40)	(50)	(60)	(70)	(80)	(90)	(100)	(110)					
4. Friction		10	10	15	15	20	20	25	25	30	30					
5. Temperature		15	15	20	25	30	35	45	55	70	85					
6. Instability		15	15	20	25	30	35	45	55	70	85					
7. Backlash		10	10	10	10	10	10	10	10	10	10					
8. Readability																
a) Height		20	20	20	20	20	20	20	20	20	20					
b) Pressure		15	15	15	15	15	15	15	15	15	15					

*NOTE: Values in parentheses are the residual errors after scale error correction for a servo altimeter.

TABLE III

ESTIMATED ALTITUDE MEASUREMENT ERRORS FOR STATIC PRESSURE PORT CALIBRATOR

Maximum Tolerances, Feet

Height x 1000 ft	0	5	10	15	20	25	30	35	40	45	50	60	70	80	90	100
1. Repeatability +	2.4	2.7	3.2	3.7	4.4	5.3	6.3	7.6	9.6	12.2	15.5	25.0	40.0	65.4	72.0	108.6
2. Hysteresis																
3. Calibration	.9	1.1	1.3	1.5	1.7	2.1	2.5	3.0	3.8	4.8	6.1	9.8	15.9	25.7	42.7	70.1
4. Pressure Stabilization	5.5	5.3	5.2	5.0	4.8	4.6	4.4	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.5
5. Thermal Zero Shift	5.5	5.3	5.2	5.0	4.8	4.6	4.4	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.5

The effective standard deviations caused by Errors 1 through 8 in Table II have been calculated, Reference 14. In the computation Errors 1 through 7 are assumed as purely random distribution, Item 8 has a limit distribution, and Item 9 has a rectangular distribution. The results for a precision altimeter are shown in Figure 2.3. The values given for a precision altimeter corrected for scale error probably represent the absolute accuracy of a calibrated precision altimeter used for flight testing.

2.2.3 Static Port Calibrator

The term "static port calibrator" is arbitrary and used in this report to cover a class of instruments incorporating precision limited range differential pressure transducers. The differential pressure gage has one side connected to a static pressure source and the other side connected to a reference pressure chamber. In operation, the reference chamber is sealed at some preselected reference pressure altitude and flight condition, and the differential pressure gage then measures the change or deviation with respect to the reference pressure. The unit is designed to operate over a small altitude range; hence it has a high degree of sensitivity and accuracy. This system can be used in conjunction with ground tracking and with pacer techniques for the calibration of static position error.

A static port calibrator system consists of components shown schematically in Figure 2.4. A small volume reference chamber is maintained at constant temperature by use of a temperature controller. This tank is connected to the aircraft static system. A reference air sample may be stored by closing a valve at the tank inlet. A limited range differential gage is located adjacent to the reference tank so it is maintained also at constant temperature. One side of the gage is exposed to the reference tank; the other side is vented to the aircraft static port. A meter located on the calibrator and a remote indicator can provide both the operator and the pilot with visual reference to the pressure differences between the static pressure system and the reference tank. The pressure readings can also be recorded on a recording oscillograph or photo panel. Details of flight calibration procedures using the static port calibrator are included in Sections 4 through 7.

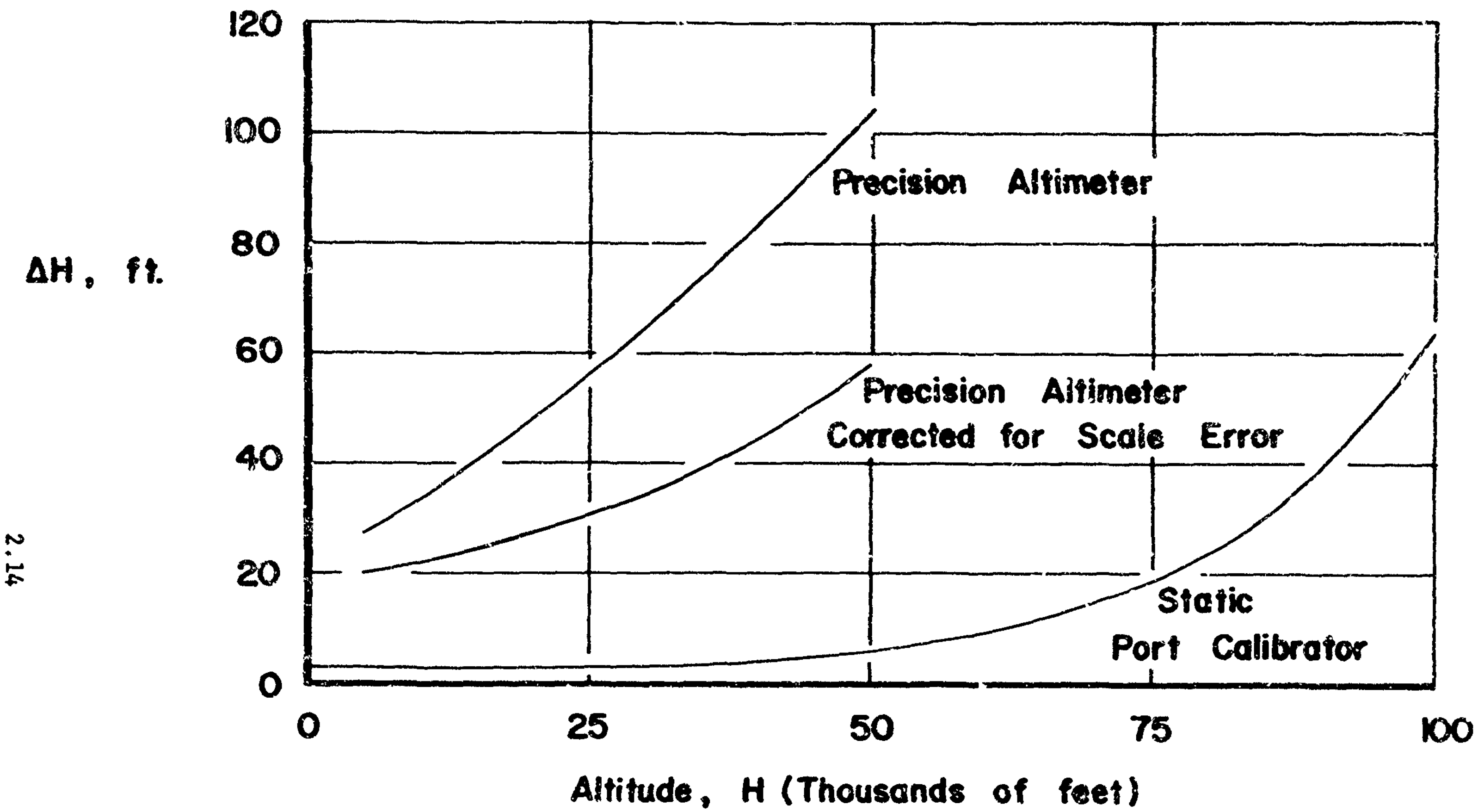


Figure 2.3

Comparison of Altimeter Measurement Accuracies for Various Altimeters

(One Standard Deviation Values)

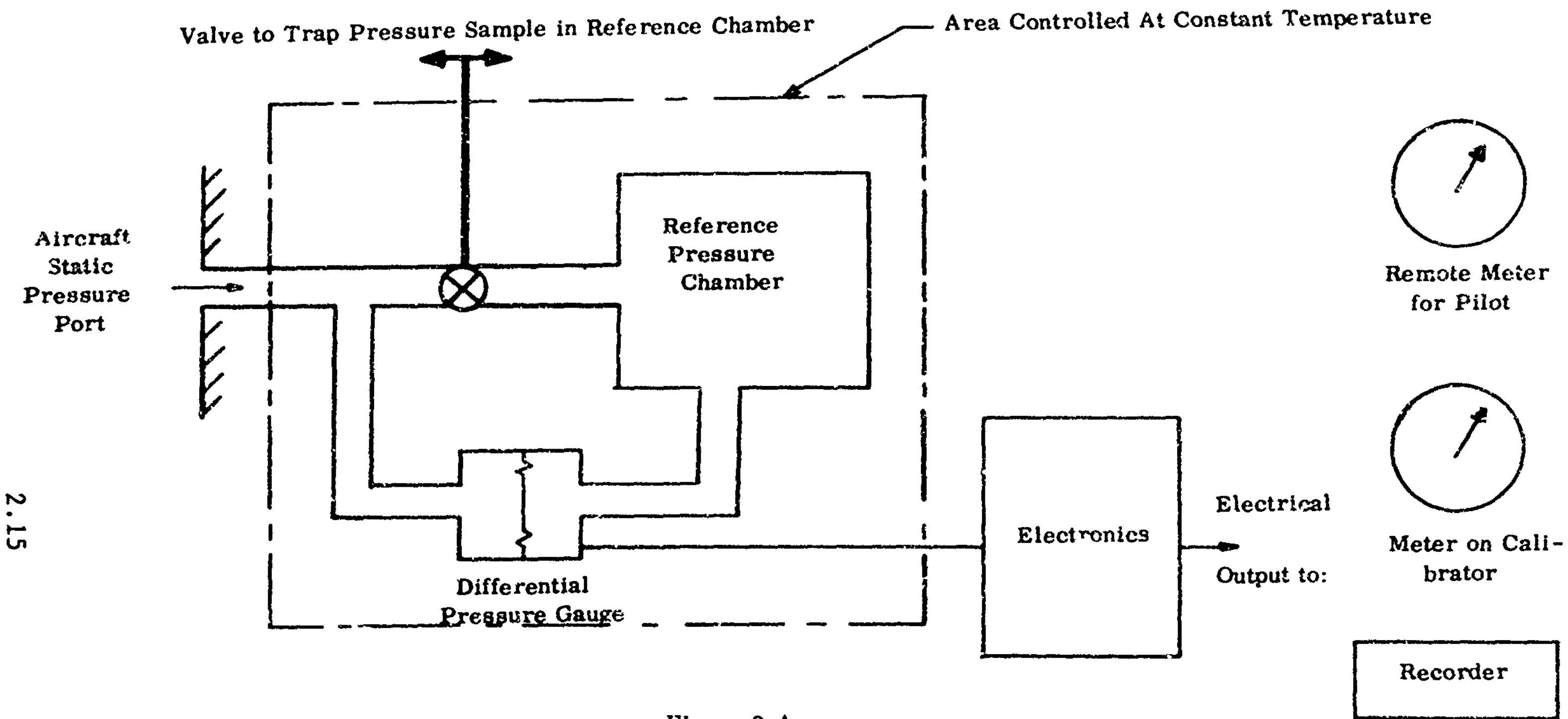


Figure 2.4

Schematic of Static Port Calibrator with Integral Reference Pressure Chamber

2.2.4 <u>Static Port Calibrator Errors</u>

In one design of a static port calibrator, a limited range electric capacitance type pressure gage is utilized. The motion of a thin stretched membrane between two capacitance plates provides variable electric output. Many of the mechanical errors associated with the conventional full range altimeter are eliminated by this type of design. The friction error is merely the infinitesimal internal friction within the stretched metal membrane. Coordination error and backlash error are also eliminated. The full scale range of the pressure sensor in one design is ± 0.25 psid for initial pressures between 0 and 20 psia. This provides an equivalent altitude range of about ± 500 feet at sea level and the range increases with increasing altitude. The sensor will provide a usable electric output for an extended range to ± 0.5 psid. The following maximum errors have been determined for this static pressure port calibrator. These errors are all of a random nature, or gaussian distribution.

1. <u>Repeatability, Drift and Hysteresis</u>: Combined repeatability, drift and hysteresis shall give errors no greater than ± 0.00125 psid. Equivalent error in terms of feet of altitude is indicated in Table III, (page 2.12).

2. <u>Pressure Stabilization</u>: Sealing of the reference pressure shall cause a pressure change of less than 0.02 percent of trapped pressure.

3. <u>Thermal Zero Shift</u>: Thermal shift shall be no greater than 0.02 percent of trapped pressure for environmental temperature change of 10°F. The errors due to pressure stabilization and 10°F temperature change are given in terms of feet of altitude as a function of altitude in Table III.

4. <u>Linearity</u>: The device is designed to provide a linear output with pressure. Deviations from the linear output are within ± 0.0025 psid. This nonlinear error is similar to the diaphragm error for a full range altimeter. The magnitude of the nonlinear error may be visualized from Table III since errors due to repeatability and hysteresis when multiplied by two represent the nonlinearity error. The sum of linearity, repeatability and hysteresis errors would be three times the

values of the first line of Table III. In actual use however, it is expected that the output from the pressure gage would be calibrated using an accurate differential measurement technique. In such a case, the accuracy of the calibration will be as shown as Item 3 of Table III, "calibration". Accuracy listed conforms to the calibration accuracy of ± 0.001 inches of mercury.

The standard deviations have been computed for the static port calibrator assuming all errors as random. Results are indicated in Figure 2.3, page 2.14. When compared to a precision altimeter corrected for scale error, the static port calibrator provides errors of approximately 1/10th of the precision altimeter.

2.3 STATIC PRESSURE SYSTEM ERRORS

This error is defined as the error in the indication of an altimeter due to the static pressure source. The error may be further sub-divided into a static pressure port error and a gas pressure transmission error. The static pressure system error equals the static pressure port error plus gas pressure transmission error.

2.3.1 Static Pressure Port Error

The error is due to the location (position) and condition of the static pressure ports (orifices) on flight vehicles.

Normally, the static pressure is sensed from a pitot-static tube mounted to the aircraft or by using pressure ports located in the fuselage of the aircraft. The pressure distribution along the axis of a typical aircraft body is shown in Figure 2.5. The symbol Δp denotes the static pressure error which is defined by the equation $\Delta p = p_1 - p$ where p_1 = local static pressure and p = true static pressure. For most flight test work, Δp is expressed as a fraction of impact pressure, q_c, (pitot pressure minus static pressure). The addition of the wing and tail surfaces alters the pressure distribution aft of the nose section as indicated by Figure 2.5. For the aircraft body complete with wings and fins, the desirable port locations are indicated by Numbers 1 through 6 of Figure 2.5.

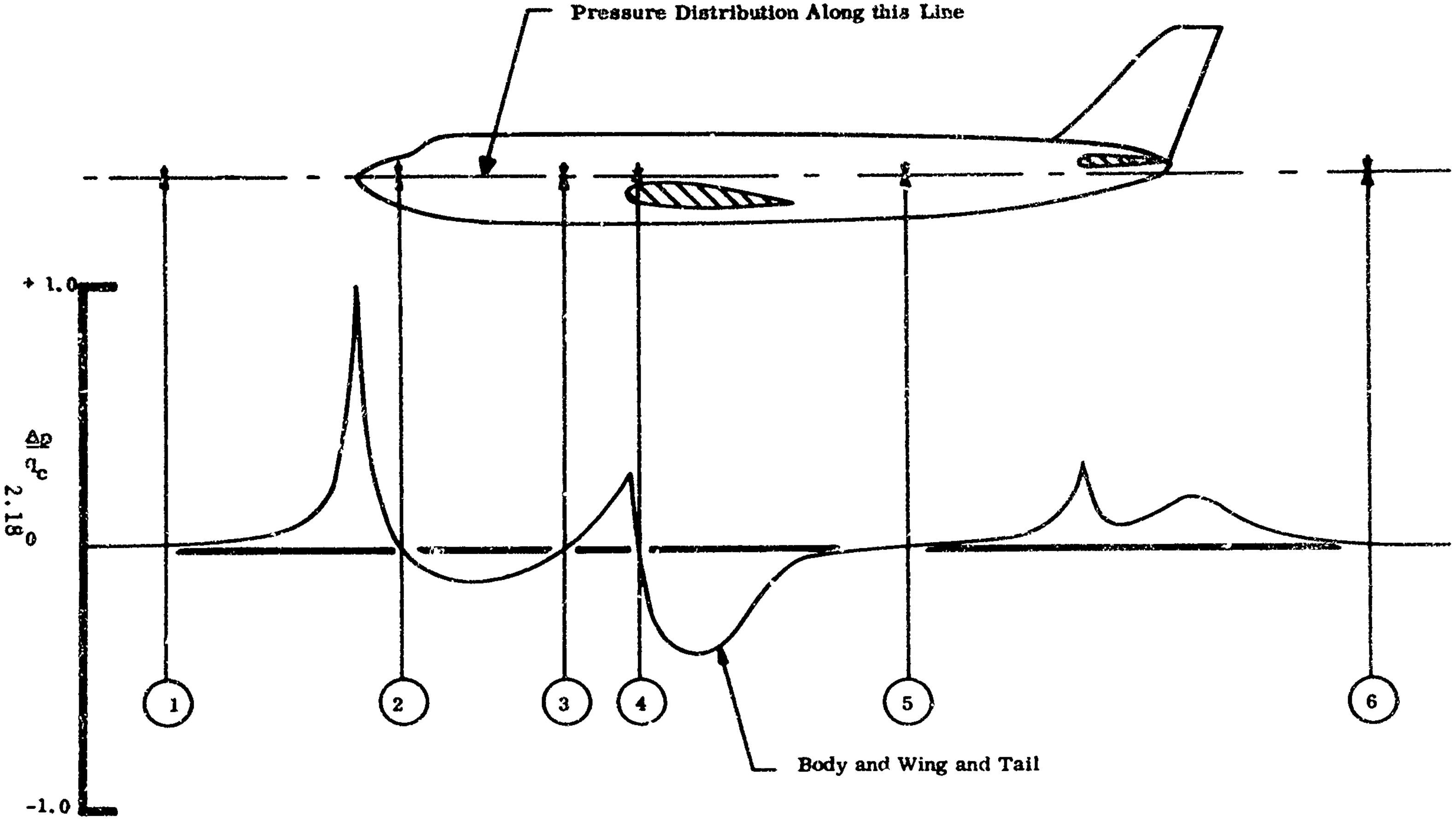


Figure 2.5

Typical Subsonic Static l ressure Distribution on Aircraft Fuselage

1 - 6 are points of minimum static pressure error

Pressure distribution around an aircraft will change as the airflow changes. This may occur primarily as a function of angle of attack of the aircraft and/or Mach number. The variation of the parameter $\Delta p/q_c$ with Mach number usually occurs above M = 0.6. The pressure will also change due to change in aircraft geometry such as the deflection of flaps and spoilers, wheel retraction or extension, and deflection of control surfaces.

The pressure at the pressure sensing port is also influenced by the surface condition in the region of the ports, References 17, 18, and 19. These skin or surface deformations due to damage or aging of the aircraft cause non-repeatability of static pressure between aircraft of a given type under identical flight conditions. Flight measurements on 6 propeller driven military type transport aircraft, Reference 15, indicated differences near sea level of 80 feet of altitude at 140 knots indicated airspeed. The difference increased with increasing indicated airspeed to 150 feet at 240 knots. New jet type transports at 240 knots IAS differed by only 20 feet, but the difference increased to 70 feet at 340 knots near sea level, Reference 15. This is equivalent to 190 feet at 30,000 feet.

On the 6 possible aircraft fuselage pressure port locations shown in Figure 2.5, locations 1, 2, 3 and 5 are the ones most commonly used. Location 1, ahead of the aircraft, is a nose boom installation used primarily by the military. In this case a pitot-static tube is supported ahead of the aircraft nose by a suitable mounting section. The distance from the nose of the aircraft to location of the static ports varies with the size of the aircraft. Usually the distance x/D, ratioed to the maximum effective fuselage diameter, varies between 0.1 to 1.0 with value near x/D = 0.5 probably being the most common. In any case the range x/D = 0.1 to 1.0 is not sufficient to obtain $\Delta p/q_c = 0$ and a static pressure error or position error exists. The longer the nose boom the smaller the error. In each case, the position error is positive, i.e., the indicated pressure is too high and the indicated altitude too low.

In addition to nose boom mounting, pitot-static tubes mounted ahead of wing leading edge or vertical stabilizer leading edge are also common, particularly in military aircraft. The most favorable pitot-static tube location is dependent on

the type of aircraft. The aerodynamic performance of pitot-static tubes varies considerably and the characteristics of the aircraft plus the tube selected determine the aerodynamic performance of the combination. Several examples of pitot-static tubes are given in Reference 18. An example of the variation of static pressure as a function of angle of attack for two common pitot-static tubes is shown in Figure 2.6. The results of Figure 2.6 indicate that each type gives a static pressure relatively insensitive to angle of attack. The performance of the military type MA-1 is seen to be slightly superior at positive angles of attack.

The variation of position error, $\Delta p/q_c$ form, for typical nose boom, wing boom, and fin boom pitot-static tube installations is shown in Figure 2.7, from Reference 20, as a function of Mach number. Worthy of note is that up to $M = 0.6$, a constant error exists for the nose boom range. A rise in error with Mach number is characteristic of all three installations. Beyond $M = 1.0$ nose boom installations will have negligible errors. Due to presence of shock waves, fin and wing booms show erratic error variations beyond $M = 1.0$ and for this reason, are generally not used above $M = 1.0$.

Most nose boom installations, using a pitot-static tube which is insensitive to angle of attack (Figure 2.6), will provide a static system also insensitive to angle of attack. This has been demonstrated by flight tests. An example is shown in Figure 2.8 at three values of x/D. The data of Figure 2.8 was obtained from Reference 18. The pressure error is shown as a function of lift coefficient (C_L). For aircraft below stall, the lift coefficient is nearly a linear function of the angle of attack. Therefore, if pressure error is constant with changing C_L, it will remain constant with changing angle of attack.

Wing boom pitot-static tube installations are generally sensitive to angle of attack due to large local flow angles. A typical variation, from Reference 18, is shown in Figure 2.8. At low values of lift coefficient (angle of attack), these installations show relatively constant error, i.e., up to $C_L = 0.7$.

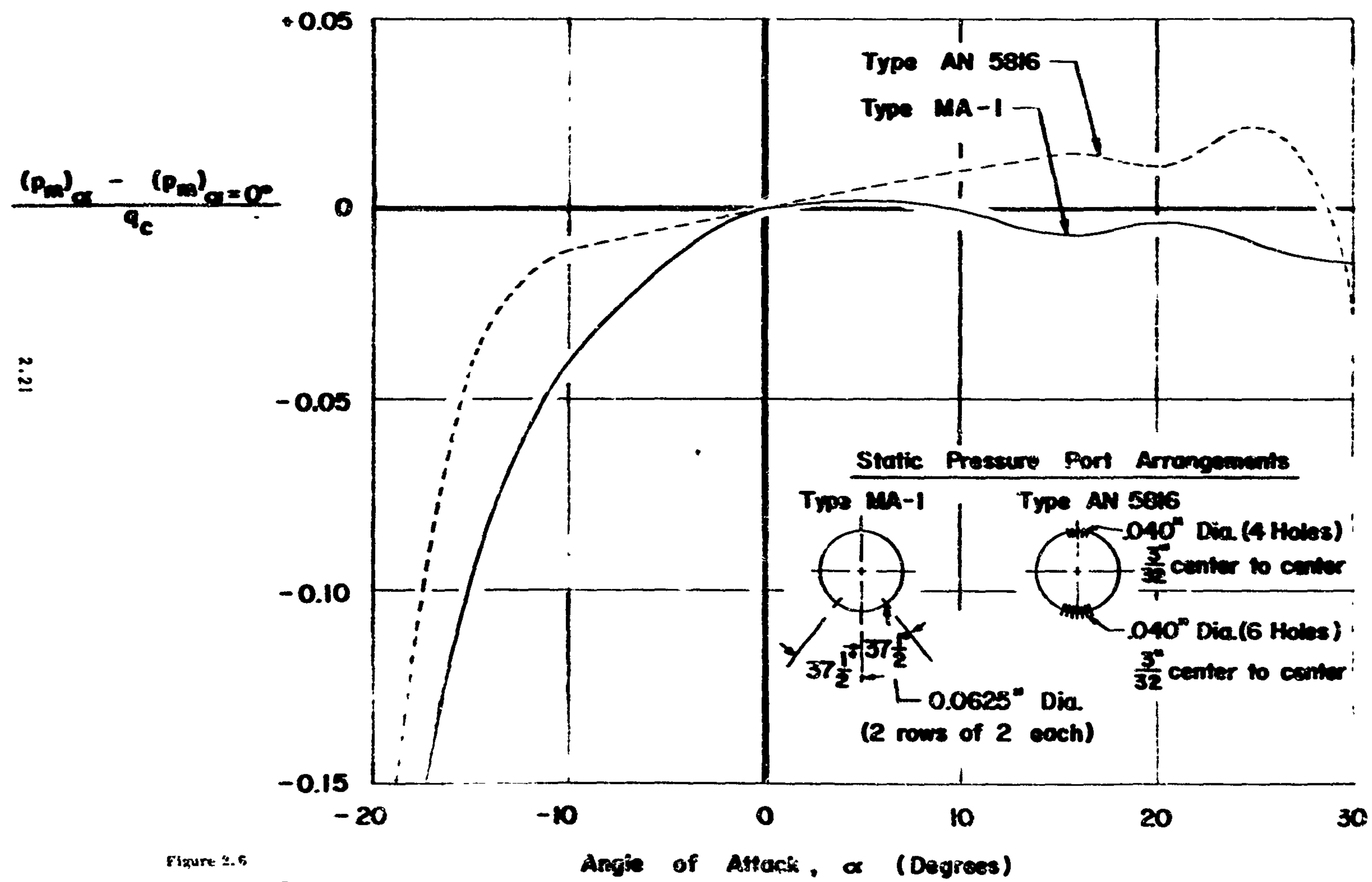


Figure 2.6

Typical Subsonic Static Pressure
Variation with Angle of Attack for Two Pitot-Static Tubes

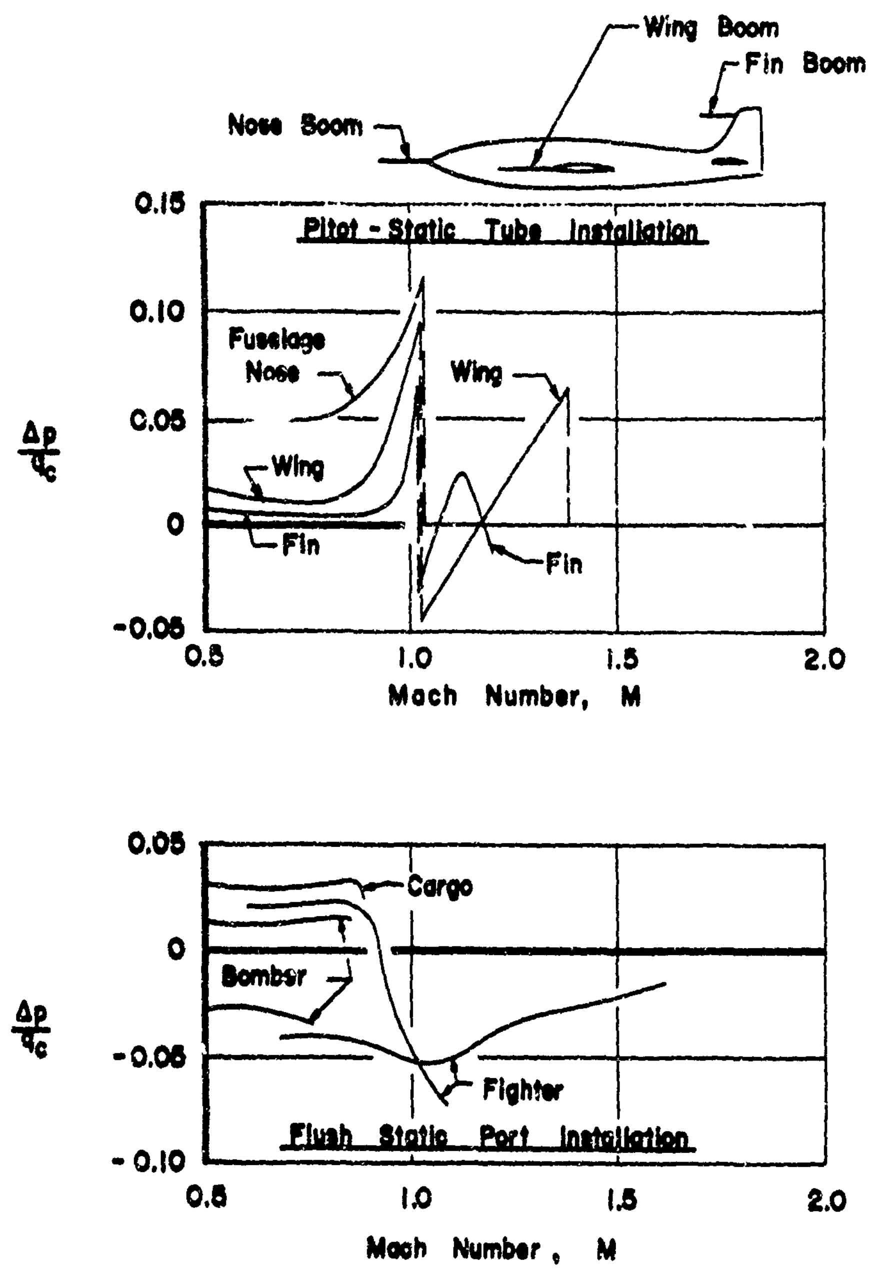


Figure 2.7
Typical Variations of Static Pressure Error
As a Function of Mach Number

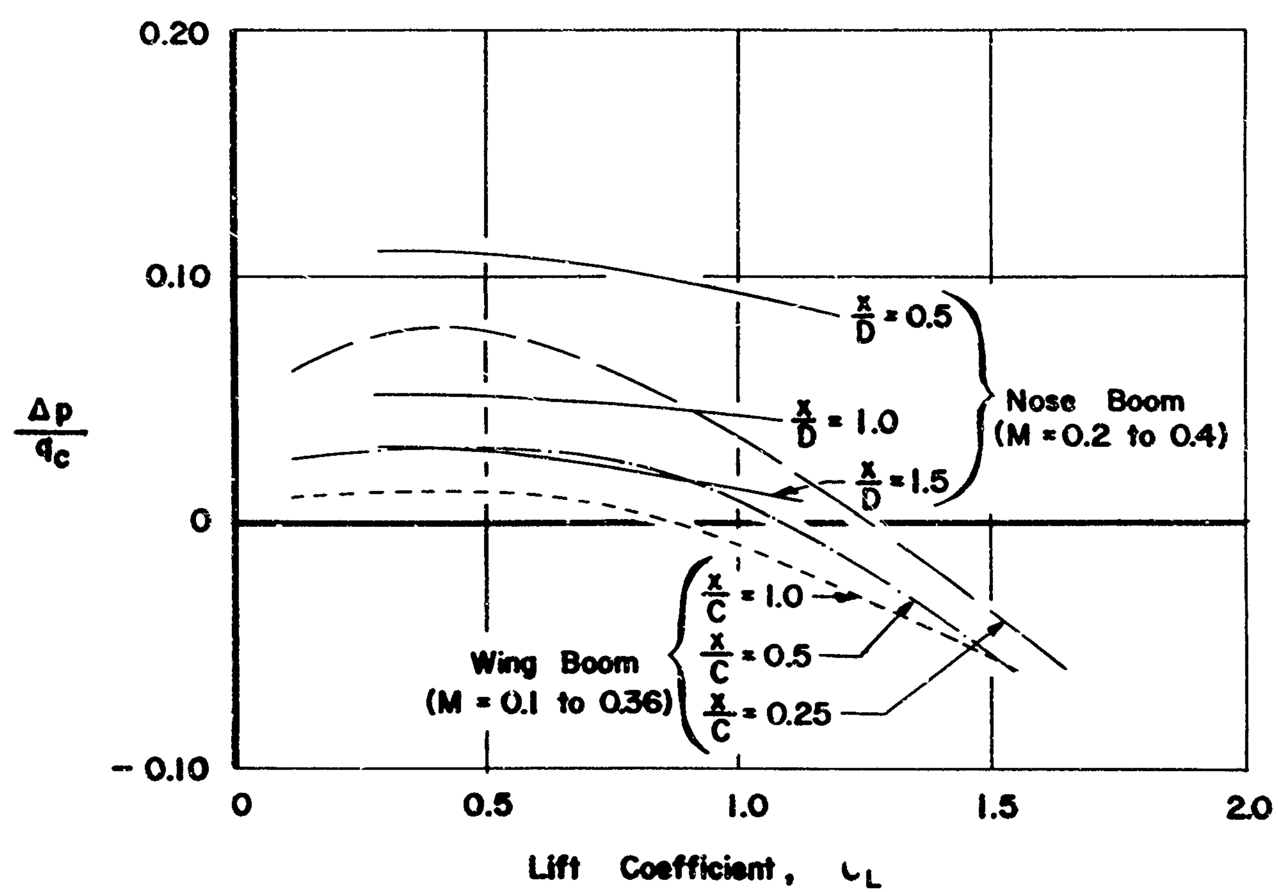


Figure 2.8

Typical Variation of Static Pressure Error Below Critical Mach Number as a Function of Lift Coefficient

(Wing Tip and Nose Boom Installations)

x = Distance Ahead of Wing or Fuselage
D = Maximum Fuselage Diameter
C = Wing Chord

Other examples of variation of static pressure for wing tip installations are shown in Figure 2.9 and 2.10. It should be noted that the normal force coefficient C_N (Figure 2.10) is nearly the same as the lift coefficient (C_L) in the range of angle of attack between zero and ten degrees. The normal force is taken perpendicular to the aircraft axis, while the lift is always perpendicular to the flight direction.

Typical aerodynamic performance of flush static pressure port installations on an aircraft fuselage are shown in Figure 2.7 as a function of Mach number, from Reference 20, and as a function of Normal Force Coefficient on Figure 2.10, from Reference 18. In the general case, static pressure measured by a flush port installation can be expected to vary slightly with angle of attack. The airframe manufacturer usually locates the pressure ports such as to provide minimum sensitivity to angle of attack, but the location is never perfect. The port location is also selected such that the error will be at a minimum value by selecting a location near one of the cross over or zero $\Delta p/q_c$ points as shown on Figure 2.5. Jet transports generally use position (3). Position (4), although a possibility, has not been used due to large angle of attack effects caused by proximity to the wing. sition (5) of Figure 2.5 has been used principally on ger. ral aviation type aircraft. Cabin vented static pressure systems are common in slow (0-100 knots) general aviation aircraft.

2.3.2 Gas Pressure Transmission Errors

These errors are caused by improper transmission of pressure from the static ports to the instruments. The errors are caused primarily by pressure leaks in the connecting pressure tubing, Reference 22. Another source of error is pressure lag in the tubing caused by obstructions such as collapsing or pinching of the tube or by undersized tubing or by excessive length of tubing. The condition of the connecting tubing is therefore important in obtaining a reliable and repeatable static pressure system.

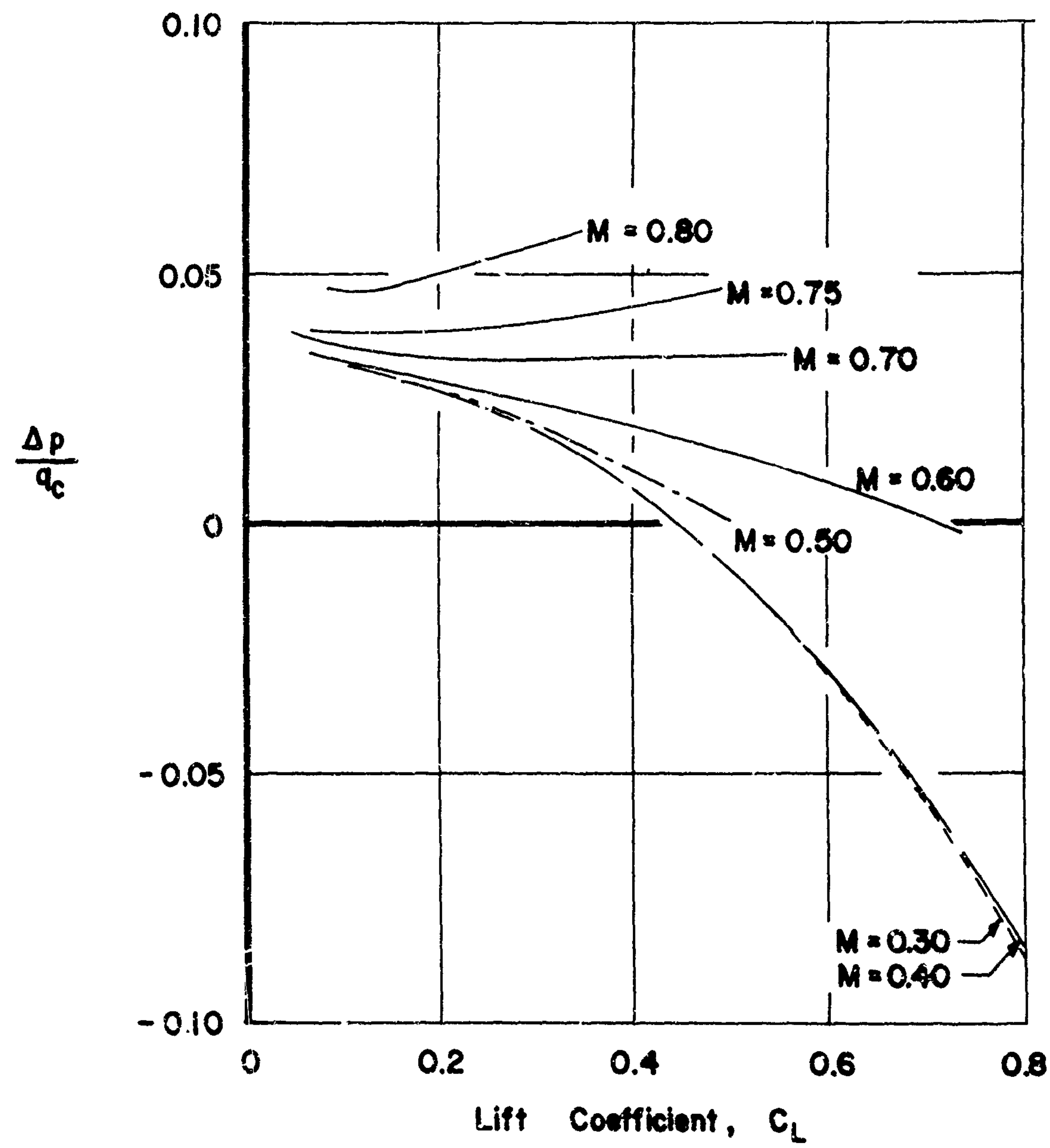


Figure 2.9

Typical Variation of Static Pressure Error With Mach Number and Lift Coefficient for Wing-Tip Boom Installation on an Unswept-Wing Airplane

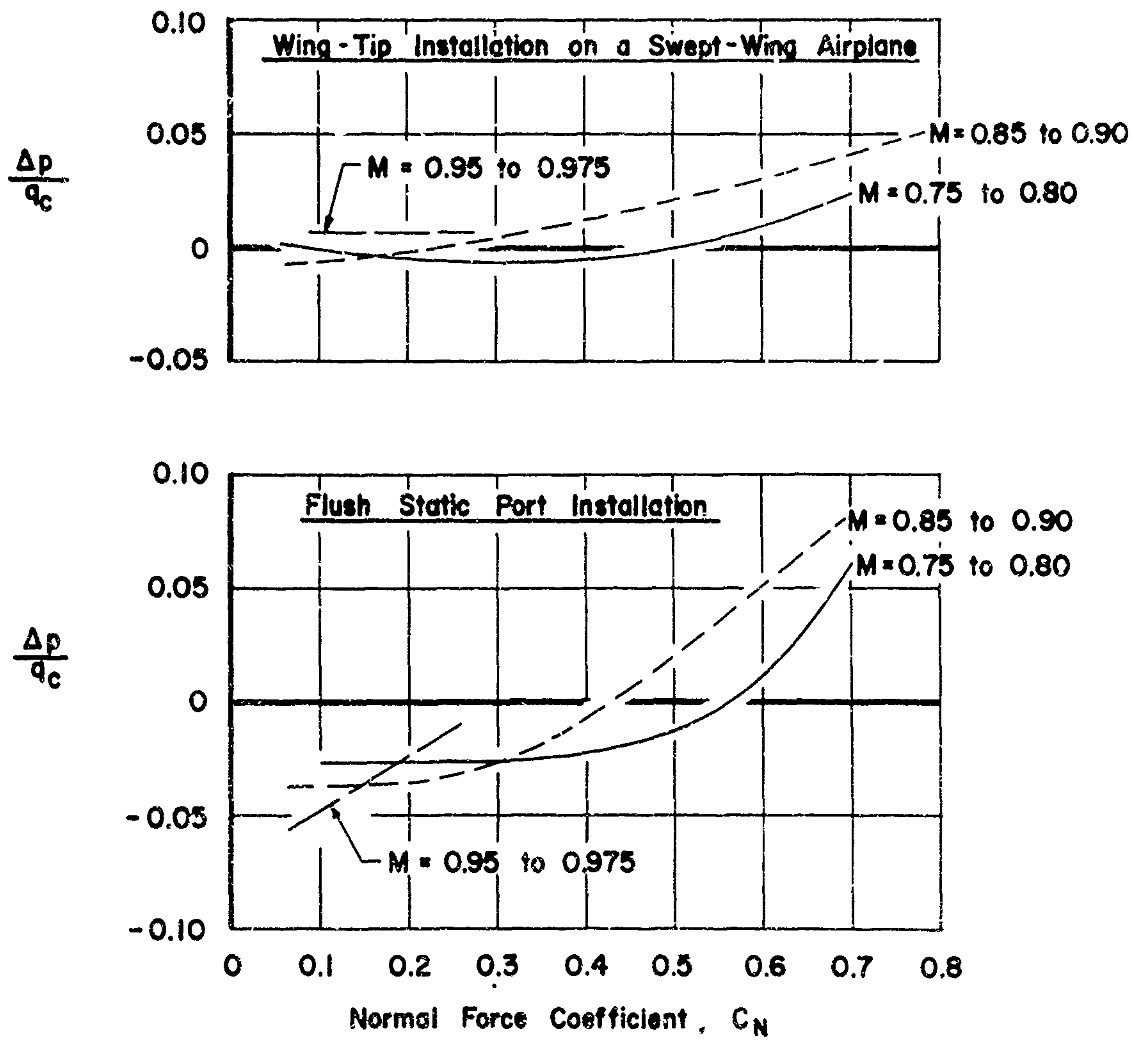


Figure 2.10

Typical Variation of Static Pressure Error with Mach Number and Normal Force Coefficient

2.4 THE INFLUENCE OF STATIC PRESSURE SYSTEM ERRORS ON AIRCRAFT INSTRUMENT SYSTEMS

The influence of the static pressure error or defect, $\Delta p/q_c$, is to cause an error in the air data systems utilizing that measurement. For example, the indicated altitude is in error by the amount shown in Figure 2.11 when $\Delta p/q_c = 0.01$. A more accurate determination of this error is shown by the detailed charts of Appendix D. An approximate altitude error expression derived from the hydrostatic equation is as follows:

$$\Delta H = -\Delta p/\rho \qquad (6)$$

ΔH = altitude error in feet,
Δp = pressure error, lb/ft^2,
ρ = density, lb/ft^3.

The airspeed error in knots due to an error of $\Delta p/q_c$ = 0.01 is shown in Figure 2.12 as a function of Mach number and altitude. In this case, a positive pressure error causes a negative airspeed error, e.g., at M = 0.5 at sea level a $\Delta p/q_c$ = +0.01 static pressure error is equivalent to an airspeed error of -1.6 knots.

The Mach number error due to an error of $\Delta p/q_c$ = 0.01 is shown in Figure 2.13. In this case, a positive pressure error causes a negative Mach number error, e.g., at M = 0.5 an error of $\Delta p/q_c$ = +0.01 causes a ΔM = -0.004.

Illustrations of typical variations for dealing with airspeed system static pressure errors are presented as Figures 2.14, 2.15, and 2.16. As an example, at Mach number 0.5 and sea level altitude we have the following:

V_c = 350 knots (from Figure 2.14),
q_c = 1.06q (Figure 2.15) i.e., the compressible impact pressure is six percent higher than the incompressible value.
q_c = 0.19P (Figure 2.16) i.e., the compressible impact pressure is 19 percent of the static pressure.

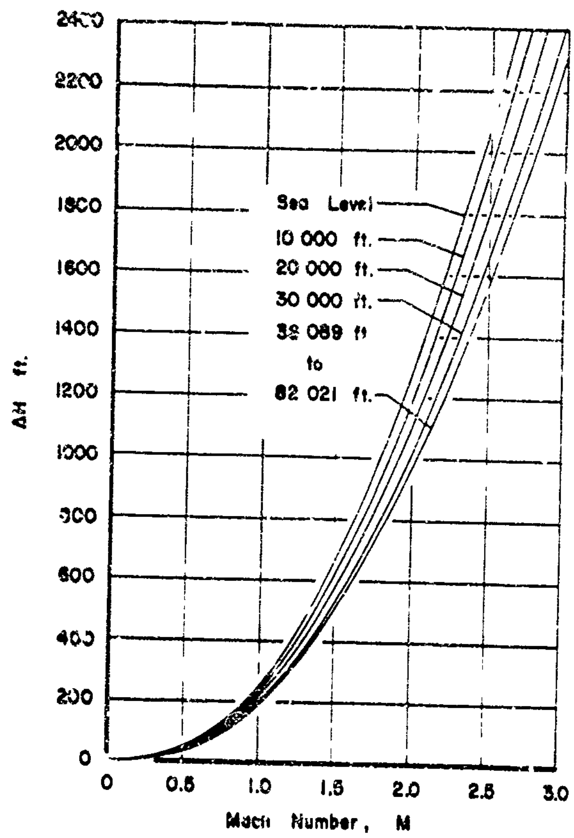


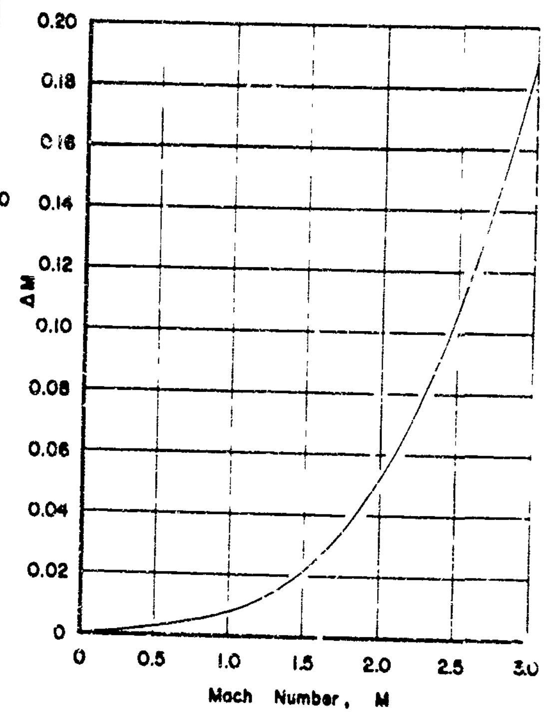
Figure 2.11

Equivalent Altitude Error for Static Pressure Error of $\Delta P/q_c = 0.01$

(computed using $\Delta H = \frac{\Delta P}{\rho}$)

Figure 2.13

Equivalent Mach Number Error for Static Pressure Error of $\Delta P/q_c = 0.01$



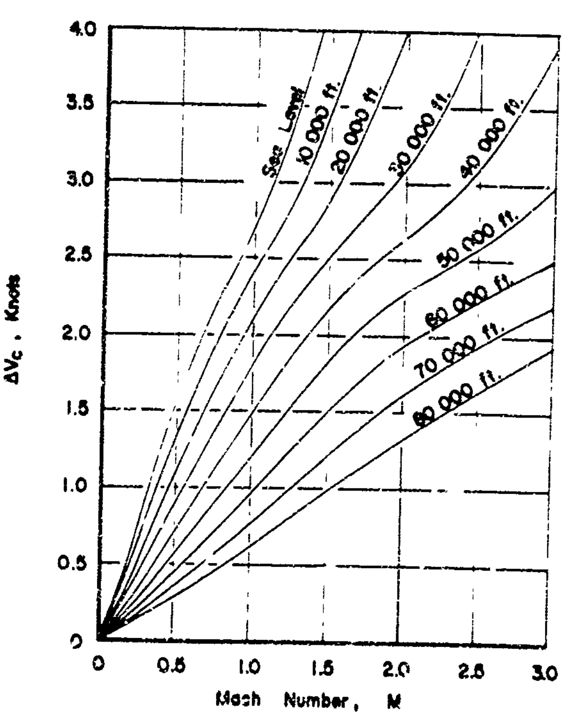


Figure 2.12

Equivalent Calibrated Airspeed Error for Static Pressure Error of $\Delta P/q_c = 0.01$

Figure 2.14

Calibrated Airspeed Versus Mach Number for Lines of Constant Altitude

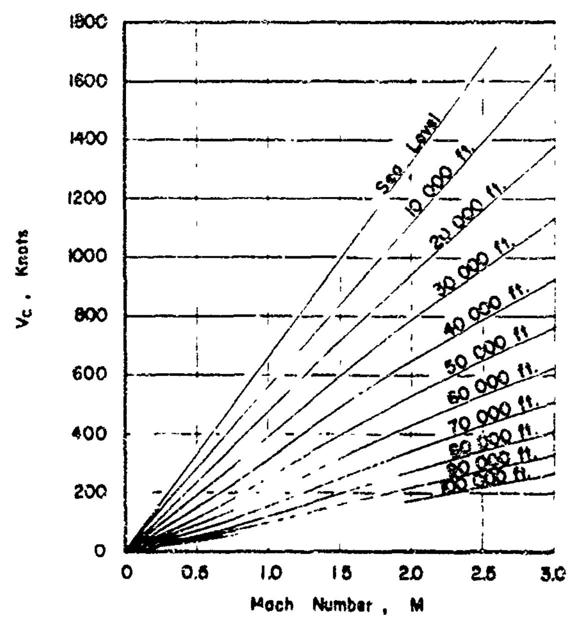
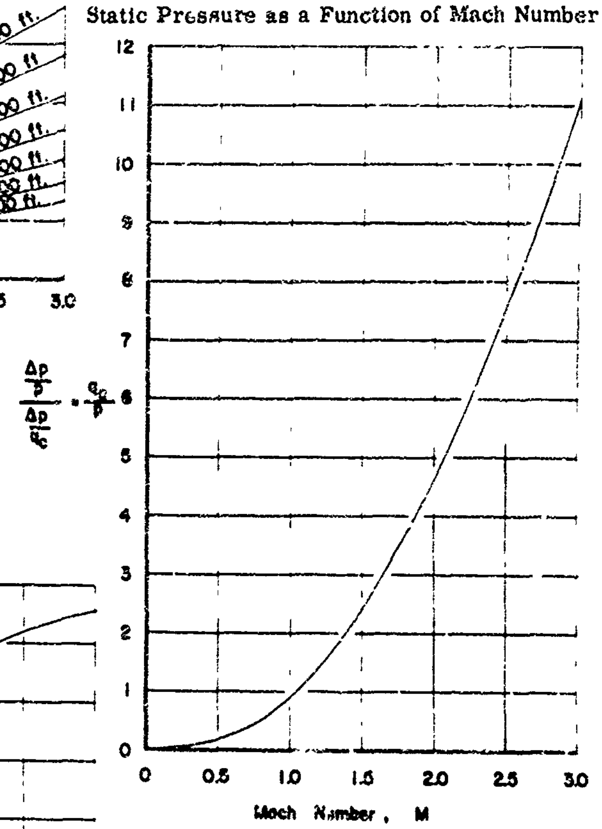


Figure 2.16

Ratio of Compressible Dynamic Pressure to Static Pressure as a Function of Mach Number



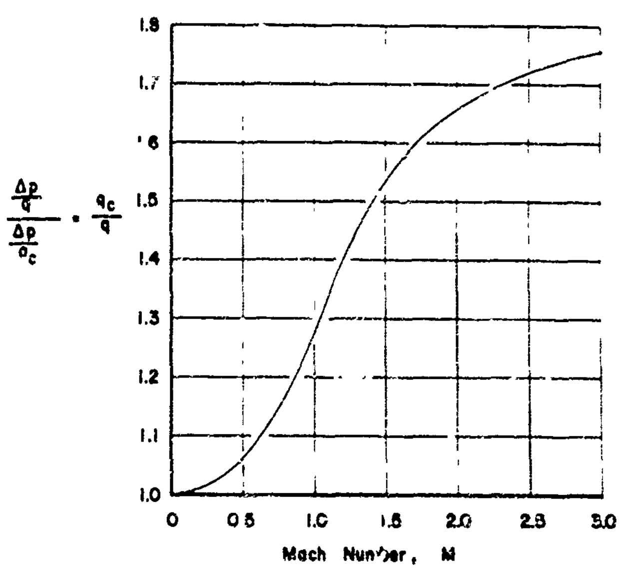


Figure 2.15

Ratio of Compressible Dynamic Pressure to Dynamic Pressure as a Function of Mach Number

More detailed conversion charts are contained in Appendix D and in Reference 22.

2.5 DESIRED CALIBRATION ACCURACY FOR AIRCRAFT STATIC PRESSURE SYSTEM

Two desired system calibration accuracies have been considered:

1a) If it is required that aircraft flight check calibration points agree within ± (30 ft + 0.0025H) feet of pressure altitude, then the accuracy of the flight test calibration method should be within ± (30 + 0.0025H)/5 feet (Figure 2.17).

1b) Estimates of USAF desired calibration accuracy were obtained directly from Figure 1 of Reference 16 and are plotted in Figure 2.17.

Two standard deviation error values are shown on Figure 2.17 for calibrated full range precision altimeters and static port calibrators. It is noted that static port calibrators can greatly improve calibration accuracy.

2.6 ANALYSIS AND PRESENTATION OF FLIGHT TEST DATA

Each of the four flight calibration methods described in detail in this report, Sections 4, 5, 6, and 7, are designed to accurately determine static pressure error, $\Delta p = p_m - p$. Pressure measured by the aircraft's static ports is p_m and p is true static pressure or ambient pressure of the air through which the aircraft flies. Placed in pressure coefficient form ($\Delta p/q_{cm}$), where q_{cm} is measured compressible dynamic pressure, the error is a primary function only of measured Mach number (M_m) and angle of attack (α) or lift. Derivations of the relationships are given in Reference 37.

For low speed flight where the effect of compressibility on pressure error may be considered negligible, $\Delta p/q_{cm}$ will be a function only of α or lift. This assumption normally holds true for $M_m < 0.6$. In equation form

$$(\Delta p)/(q_{cm}) = f_1(\alpha) \qquad (7)$$

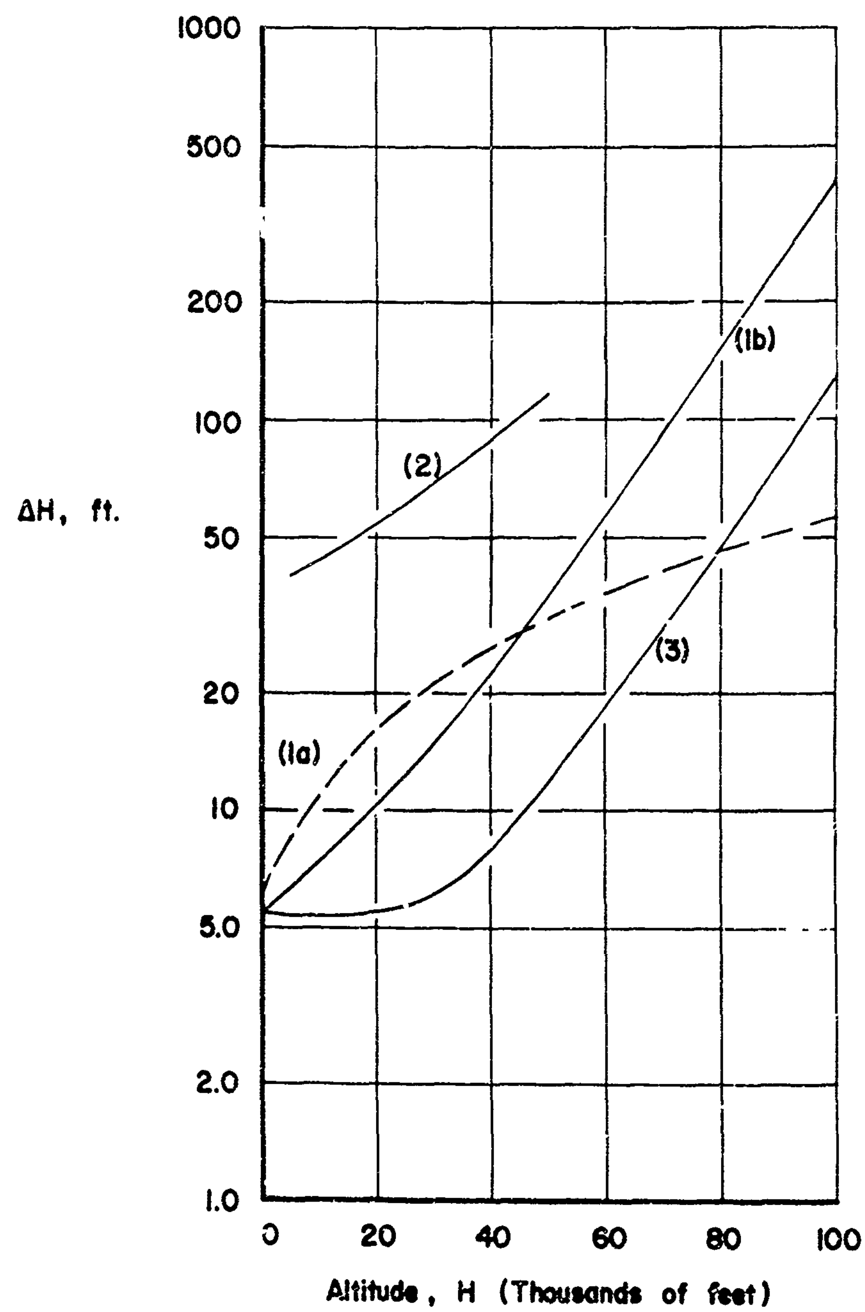


Figure 2.17

(1a) Overall Desired Calibration Accuracy (30 feet + 0.0025H) / 5.

(1b) Overall Desired Calibration Accuracy, from Reference 16.

<u>Two Standard Deviation Error Values for:</u>
(2) Calibrated Full Range Altimeter, and
(3) Static Port Calibrator

or $(\Delta p)/(q_{cm}) = f_2 (V_m, nW)$ (8)

where V_m = measured airspeed,
n = load factor ($n = 1$ when lift equals gross weight),
W = aircraft gross weight.

Low speed flight data points are therefore usually presented on graphs in the form $\Delta p/q_{cm}$ as a function of measured airspeed (V_m) and, if large variations are noted, for lines of constant gross weight or in the form $\Delta p/q_{cm}$ as a function of angle of attack (α).

Flight test data obtained above Mach number 0.6, medium subsonic, transonic, and supersonic range, will in general depend on both Mach number and angle of attack. In equation form

$$(\Delta p)/(q_{cm}) = f_3 (M_m, \alpha) \quad (9)$$

or

$$(\Delta p)/(q_{cm}) = f_4 \left(M_m, \frac{nW}{\delta_m}\right) \quad (10)$$

where δ_m = pressure ratio (p_m/p_{sl}) corresponding to H_m.

Data points obtained above Mach number 0.6 should therefore be presented on graphs in the form $\Delta p/q_{cm}$ as a function of M_m and, if a dependency exists, for lines of either constant nW/δ_m or angle of attack (α).

Fairing curves through the flight test data represents the final data evaluation. These faired curves are used for air data computer corrections, as described in Section 2.6.2. To make up altimeter correction cards, $\Delta p/q_{cm}$ values from the faired curves are converted to altitude position error as described below in Section 2.6.1.

2.6.1 Altimeter Correction Cards

Altimeter position error correction cards contain values of measured altitude ($H_m = H - \Delta H_c$) or altitude position error correction (ΔH_c) as a function of true altitude (H) and measured airspeed (V_m) or Mach number (M_m). They are used by the pilot to correct the altimeter reading to true pressure altitude (H).

If an altimeter instrument correction card listing altimeter scale error (ΔH_{ic}) as a function of indicated altitude (H_i) is also needed, the pilot must apply ΔH_{ic} correction before he applies the position error correction:

$$H_m = H_i + \Delta H_{ic} \tag{11}$$

$$H = H_m + \Delta H_c \tag{12}$$

For pilot convenience it appears desirable to combine both ΔH_{ic} and ΔH_c as one correction on a single altimeter correction card. In this case, it is necessary to make up a new card every time an altimeter is replaced or recalibrated.

Small position error corrections can be obtained directly from the following equation:

$$\Delta H_c = \frac{\Delta p}{\rho G} \tag{13}$$

where ρ is mass density at the desired pressure altitude (H) and G is the gravitational constant of the U. S. Standard Atmosphere, Reference 6. Using $G = 32.17405$ feet/second^2 and σ = standard day air density ratio at H,

$$\sigma = \rho/\rho_{sl}$$

we obtain,

$$(\Delta H_c)_o = 924.834 \; \Delta p/\sigma \tag{14}$$

when $(\Delta H_c)_o$ is in feet and Δp is in inches of mercury. The density ratio, σ, is included in Table C-III as a function of altitude, H_m.

A noticeable error will exist if Equation 20 is used to determine values of ΔH_c greater than about ± 500 feet. However, a correction can be easily applied. The procedure is as follows:

1) Determine $(\Delta H_c)_o$, using Equation 20.
2) If $(\Delta H_c)_o \leq \pm 500$ feet, $(\Delta H_c)_o = \Delta H_c$ can be assumed.
3) If $(\Delta H_c)_o > \pm 500$ feet, add the correction $\Delta H_c - (\Delta H_c)_o$ from Chart D-I to $(\Delta H_c)_o$ to obtain the true position error correction, ΔH_c.

The static pressure error ($\Delta p = p_m - p$) used in Equation (20) can be obtained by multiplying the pressure error coefficient $\Delta p/q_{cm}$ by q_{cm} at a specific measured airspeed (V_m). Measured compressible dynamic pressure (q_{cm}) as a function of V_m is given in Chart D-3. When Equation (2) is used to find altitude error at a specific Mach number and altitude, q_{cm} is found from the relationship $q_{cm}/p_m = (p_{t'm}/p_m)-1$. The ratio $p_{t'm}/p_m$ is obtained from Table C-II or Reference 28 at the specific measured Mach number, M_m. True static pressure (p) corresponds to the specific true pressure altitude (H), from Table C-I.

On position error correction cards for low speed flight ($M_m < 0.6$), measured pressure altitude ($H_m = H - \Delta H_c$) is usually presented in a table for rows of constant measured airspeed (V_m) and columns of constant true pressure altitude (H). An example is shown on Table IV. Values of V_m and H should represent the full operating range of the aircraft. If the flight test determined graph of $\Delta p/q_{cm}$ vs V_m does not vary appreciably with aircraft gross weight, the correction card can represent conditions of nominal gross weight. If a large variation with gross weight is found, the correction card should contain several tables, each table representing a specific gross weight (nW) or angle of attack (α). If the position error correction (ΔH_c) changes appreciably for take-off or landing configurations of the aircraft (flaps, landing gear, etc., extended), separate tables should be shown on the correction card to represent these configurations.

For aircraft with flight capabilities above M = 0.6, the position error correction will probably exhibit some compressibility effects. If at constant M_m the pressure error $\Delta p/q_{cm}$ also depends significantly on lift coefficient or angle of attack, the position error correction card should present measured pressure altitude (H_m) in a table for rows of constant measured Mach number (M_m) and columns of constant true pressure altitude (H) for a constant angle of attack (α) or specific gross weight (nW). An example is also shown on Table IV. This table will be used for high speed cruise conditions and can be a continuation of the low speed table (H_m vs V_m and H) used for hold, loiter, and landing and take-off flight conditions.

2.6.2 Air Data Computer Corrections

Air Data Computer Corrections for static pressure error are usually provided in the form of continuous graphs, similar to those explained at the beginning of this section, for the final presentation of flight test calibration data points. The parameters on the graphs are:

(1) $\Delta p/q_{cm}$ vs V_m at constant nW

or, $\Delta p/q_{cm}$ vs α

for aircraft with flight capabilities below about $M = 0.6$, and when $\Delta p/q_{cm}$ does not depend on compressibility influence;

(2) $\Delta p/q_{cm}$ vs M_m at constant $(nW)/(\delta_m)$ or α for aircraft with flight capabilities above $M = 0.6$.

In the air data computer the static pressure error coefficient $(\Delta p/q_{cm})$ or pressure ratio (p_m/p) is programmed as a continuous function of M_m or V_m. Some computers can also correct for angle of attack variations. If the angle of attack correction is not needed (or is not available) in the computer, a nominal aircraft weight is used to provide a single correction curve $\Delta p/q_{cm}$ as a function of V_m or M_m. The compressible dynamic pressure (q_{cm}) is obtained in the computer from the measurement $q_{cm} = p_{t'm} - p_m$; $p_{t'm}$ is measured pitot pressure and p_m is measured static pressure. Measured airspeed (V_m) is computed from q_{cm}, and measured Mach number (M_m) is computed from the ratio $p_m/p_{t'm}$. Usually air data computers have no correction capabilities for an error in pitot pressure. Therefore pitot tubes and pitot tube mounting locations should be selected to have negligible pitot pressure error. Fortunately, on most aircraft this is easily attainable.

TABLE IV

PILOT'S AND CO-PILOT'S STATIC SYSTEM CALIBRATION
AIRCRAFT: REC 525Z, Number Y2018Z

NOTE: This Calibration Does Not Include Altimeter Instrument Error

Measured Airspeed (Knots)	True Pressure Altitude (Feet)								
	0	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000
	Measured Pressure Altitude (Feet)								
I. Aircraft Configuration: Clean									
200	15		10,020		20,030		30,045		
220	20		10,030		20,035		30,055		
240	25		10,030		20,045				
260	30		10,040		20,055				
280	35		10,045						
300	40		10,050						
320	45		10,060						
340	50		10,065						
360	55								
380	60								
400	70								
II. Aircraft Configuration: Partial Flaps									
160	15	5,020	10,020	15,025					
180	20	5,025	10,030	15,030					
200	25	5,030	10,035	15,040					
220	30	5,035	10,040	15,050					
III. Aircraft Configuration: Partial Flaps Plus Gear Extended									
140	5	5,005	10,005						
160	5	5,005	10,005						
180	5	5,005	10,010						
200	5	5,010	10,010						
IV. Aircraft Configuration: Full Flaps Plus Gear Extended									
120	5	5,005	10,005						
140	5	5,005	10,005						
160	5	5,005	10,005						
180	5	5,005	10,010						

V. Aircraft Configuration: Clean

Measured Mach Number	True Pressure Altitude (Feet)				
	0	10,000	20,000	30,000	40,000
	Measured Pressure Altitude				
.30	20				
.40	30	10,025			
.50	45	10,045	20,040		
.60	70	10,065	20,060	30,055	
.70	70	10,065	20,060	30,055	40,050
.75	45	10,040	[illegible]	30,035	40,035
.80	-20	9,980	19,985	29,985	39,085

SECTION 3

GENERAL DESCRIPTIONS OF SEVERAL AIRCRAFT STATIC PRESSURE CALIBRATION METHODS

3.1 INTRODUCTION

Several experimental methods have been developed for the calibration of aircraft static-pressure systems. It is the objective of these methods to determine the static system error over the speed, altitude, and weight range for the aircraft. The methods can be sub-divided into two divisions.

The first division includes all calibration methods which utilize pressure measurements only. These may use pressure altitude instruments such as altimeters, absolute pressure sensors, or differential pressure sensors. One example is calibration by the pacer method with both the test aircraft and the pacer aircraft using pressure sensitive instruments. Another example is calibration by the trailing cone method with a pressure differential sensor used between the test system and the trailing cone.

A second division of methods includes those which use geometric altitude or altitude differences to accomplish the calibration. The geometric altitude is converted into pressure terms to enable computation of position error. One example is calibration by the camera fly-over method with the altitude of the aircraft above the camera determined from a photograph. Another example is calibration using ground based radar tracking equipment with geometric altitude changes indicating changes in pressure and pressure altitude.

Four calibration methods are generally described in this section. Two methods require the use of pressure sensitive instruments only. Two methods require geometric altitude measurements. A brief comparison of the methods follow in this section with more details on the individual methods included in Section 3.2 through 3.6.

3.1.1 Personnel Requirements

The follow[illegible] a listing of personnel that may be required for aircraft s[illegible] [illegible]ssure calibration.

General Engineer: A graduate aeronautical, mechanical or electrical engineer. Flight and instrumentation experience is desirable. In some cases the engineer may serve as the qualified flight observer.

Qualified Observer: A general engineer, pilot, instrument mechanic or person familiar with the instruments being recorded and operation of the equipment.

General Pilot: An experienced pilot with a minimum of 500 total pilot flight hours including at least 5 hours in the aircraft used during calibration.

Test Pilot: An experienced pilot with a minimum of 2000 total pilot flight hours including at least 10 hours in the aircraft used during calibration.

The size of the test crew will depend somewhat on the calibration method used. Detailed listings are contained in Sections 3.2 through 3.6. A general engineer is required for the planning of all flight test programs. The engineer may serve as the flight observer, especially during early check out phases. The flight observer is responsible for executing the flight test program. He must be familiar with the details of the test method and operational manual of the aircraft under test. Before any flight, he must brief the pilots and observers on all pertinent details of procedures of the calibration method. The flight observer makes out the flight test plan and provides data forms used during testing.

3.1.2 Flight Time Requirements

The flight time required will depend on the extent of the calibration and the calibration method selected. The extent of the calibration will depend on whether calibration is to serve as a check or is to completely define the static pressure error for all flight conditions. For the latter, an extensive program

should be required consisting of flying the aircraft in the normal landing, normal approach, and normal level flight (clean) configurations. Tests should be conducted over the safe speed range for each configuration. Three speeds for the landing and approach configurations and five speeds for the clean configuration are recommended. Testing of landing and approach modes should be done at altitudes less than 10,000 feet. For aircraft limited to flight altitudes of 20,000 feet or less and Mach numbers of 0.6 or less, calibration in clean configuration may be accomplished at any convenient altitude. For aircraft normally flying above 20,000 ft., additional testing in the clean configuration should be accomplished in 10,000 feet increments.

A minimum of three data points shall be taken at each test condition.

For planning purposes Table VI shows a comparison of time requirements for the various calibration methods described in Sections 3.2 through 3.6.

<u>Example of Typical Check Type Calibration Program</u>: A commercial airline must run a calibration check on each aircraft at 30,000 feet with aircraft clean and in the normal approach configuration with gear retracted.

At normal approach configuration, tests are to be conducted at 500 feet altitude using camera fly-over method at 140, 160 and 180 knots requiring 9 test points (3 at each condition). Using Table VI total time can be expected to be:

Step No.	Time Required (min.)
1	5
2	5
3	9 x 8 = 72
4	5
5	5

Total Flight Time = 92 minutes

At aircraft clean (30,000 feet) radar tracking method is used at 200, 225, 250, 275, 300 KIAS requiring 15 test points

TABLE VI

COMPARISON OF TIME REQUIREMENTS FOR VARIOUS FLIGHT CALIBRATION METHODS*
(Minutes)

Step No.	Operation	Camera Fly-Over or Tower Fly-By	Pacer Aircraft	Radar** Tracking	Trailing Probe
1	Prior to Take-Off	5	0	0	0
2	Time to First Run	5	15	25	10
3	Time per Run	8*	3	4*	2
4	Return to Base	5	10	15	10
5	After Landing	5	0	0	0
	Time for 30-Point Calibration	260	115	160	80

*Estimates for large aircraft, could be less for small aircraft.
** Radar tracking method also requires one of the other three methods of calibration.

For camera Fly-Over and Tower Fly-By procedures, a 5-minute allowance is included for data recording before and after flight. For pacer and radar tracking method, the pacer and tracking equipment are assumed located at the take-off point of the test aircraft. If test and pacer must rendevous or radar is remotely located, "time to first run" must be significantly increased. Rates of data collection (3) may vary depending on atmospheric and air traffic conditions.

(3 each speed). Using Table VI the total flight time can be expected to be 85 minutes.

Step No.	Time Required (Min.)
1	0
2	15
3	15 x 4 = 60
4	10
5	0

Total Flight Time = 85 minutes

It is thus seen that two hours and 57 minutes are required for the two tests.

3.2 CAMERA FLY-OVER CALIBRATION METHOD

3.2.1 General Description of the Method

In this calibration method, the height of the test aircraft is measured by photographing it as it flies directly overhead, within a range of 100 to 500 feet above the camera. Using previously measured wing-span of the aircraft and calibrated focal length of the camera, the height of the aircraft above the camera can be accurately determined. The pressure is measured both at the camera site and in the aircraft using calibrated pressure instruments. Temperature is also measured at the camera site. Using the measured height, the true static pressure is calculated at the fly-over elevation. The calculated pressure is compared with the actual measured pressure in the aircraft. The pressure difference represents the static pressure error of the aircraft at the particular Mach number, airspeed, weight, and angle of attack during the fly-over.

This method should only be attempted in smooth air with constant-power-setting unaccelerated flight. Flights should be conducted over the safe airspeed range of the aircraft as obtained from the aircraft operational manual. Recommended fly over altitude is four wing spans above the camera. Because of the close ground proximity, maximum airspeed may be restricted. The method is recommended for aircraft with altitude capability less than 20,000 feet and maximum Mach number of 0.6. Although

all flights are performed near ground level, pressure error predictions can be extended to 20,000 feet altitude over the speed range of this aircraft with high reliability. Aircraft with altitude range in excess of 20,000 feet and/or speeds in excess of Mach number 0.6 may use this method of calibration, but, in addition, will be required to use one of the other three basic methods at higher speeds and altitude.

3.2.2 Accuracies Expected

This method has proven to be reliable and accurate, (References 15, 24, and 25). Predicted accuracy of the fly-over calibration with full range precision altimeter, selected for accuracy and carefully calibrated for with scale error corrections, has been predicted as 17.3 feet at sea level and independent of flight speed, (Reference 16). Utilizing a differential pressure gage or static port calibrator with recorder, the over-all predicted accuracy for this fly-by method is 5.4 feet at sea level and independent of flight speed (Reference 16). The term "static port calibrator" is arbitrary and is used in this report to cover a class of instruments incorporating precision limited range differential pressure transducers.

For aircraft flying within the range of 0 to 20,000 feet of altitude and less than 0.6 Mach number, flight tests may be conducted using camera fly-over method at specific values of indicated airspeed. If the tests are performed at sea level, the accuracy at altitude may be calculated by multiplying by densit ratio ρ_{SL}/ρ. Results are shown in Table VII.

TABLE VII

PROBABLE CALIBRATION ACCURACY AT ALTITUDE FOR LOW SPEED AIRCRAFT (M <0.6) AT CONSTANT ANGLE OF ATTACK

Altitude (Feet)	ρ_{SL}/ρ	ΔH_1, Feet (±)	ΔH_2, Feet (±)
0	1.00	17	5
5,000	1.16	20	6
10,000	1.35	24	7
15,000	1.59	27	8
20,000	1.88	32	10
25,000	2.2	38	11

ΔH_1 = Altitude error using full range precision altimeter for camera fly-over method.

ΔH_2 = Altitude error using static port calibrator for camera fly-over method.

ρ_{SL}/ρ = Ratio of density at sea level to density at altitude.

The accuracy shown in Table VII can be realized if no gross errors exist in the data measuring process. In order to insure good accuracy, it is essential that each test point be repeated at least three times.

3.2.3 Equipment Required

The following is a listing of general equipment needed for camera fly-over calibration method:

(1) Camera: A precision camera of the type used for aerial reconnaissance and mapping should be used. A manually operated single exposure camera is satisfactory. Two cameras of this type which have proved to be acceptable are the F-8 (Reference 24) and the K-24 (Reference 25).

(2) Voice Communication Equipment: Ground operator at the camera could use a mobile battery operated transceiver to communicate with the aircraft under test. Frequency must be compatible with that used by the aircraft.

(3) Barometer: A precision Aneroid barometer or a precision altimeter is required to record barometric pressure and pressure changes at the camera location.

(4) Thermometer: A laboratory precision grade thermometer will be required to monitor temperature at the camera location.

(5) Instrument Shelter: An instrument shelter is needed to house the barometer or altimeter and thermometer.

(6) Clock: A clock or watch is needed for time coordination of the test data.

(7) Altimeter: Either a calibrated altimeter or a static port calibrator will be installed in the test aircraft.

(8) Airspeed Indicator: A precision airspeed indicator with known calibration and repeatability shall be installed in the test aircraft.

3.2.4 Ground Environment

It conveniently happens that the ground environment necessary to take-off and landing of aircraft matches the requirement for camera fly-over method of calibration. The above statement is particularly true if the upper limit on flight speed is regulated to 300 knots and below. Also, it generally follows that aircraft with speeds in excess of 300 knots will have altitude capabilities in excess of 20,000 feet and Mach number capabilities in excess of Mach number 0.6. Therefore these aircraft must definitely be calibrated under altitude conditions using an alternate method in addition to the camera fly-over method. Only in the case of calibration of pacer-type aircraft should it be necessary to fly in excess of 300 knots indicated over the camera.

3.2.5 Personnel Required

General Engineer
Qualified Flight Observer
Qualified Ground Observer
General Pilot

3.2.6 Summary of the Method

Advantages

1) Good Accuracy.
2) Requires only test aircraft be flown.
3) Results can be used to 20,000 feet altitude and Mach number to 0 6.

Disadvantages

1) Flight close to ground may restrict upper speed limit.
2) The higher turbulence usually present may affect the accuracy when compared to higher altitude test methods.
3) Slow data collection rate (8 to 15 points/hr, Table VI).
4) Requires a 3-man test crew, usually.
5) Results should not be used to predict performance above 20,000 feet altitude or Mach numbers greater than 0.6.
6) Results are not available until film is developed.

3.3 TOWER FLY-BY CALIBRATION METHOD

3.3.1 General Description of the Method

In this method, the height of the test aircraft is measured by triangulation. The aircraft flies by a tower or tall building at a height within a range between 100 and 500 feet above the ground. The aircraft is sighted through a reference grid arrangement at or near the tower, by a camera or eye-piece located in the tower, to determine elevation angle. The height of the aircraft above or below a fixed point in the tower is determined by triangulation. The horizontal distance of the aircraft from the tower must be accurately known. This is usually accomplished by having the aircraft fly down the centerline of a runway located in front of the tower. The method requires that an accurate survey between eye-piece or camera, reference grid, and runway centerline be performed for both horizontal and vertical distances. Deviations from the prescribed centerline flight path will result in errors unless

the flight level and eye-piece are the same elevation. In some cases, lateral error is determined and corrected for. Such corrections require additional instrumentation. Because of the close ground proximity, maximum speed may be restricted.

3.3.2 Accuracies Expected

Expected accuracies are about the same as for Camera Fly-Over Method, Section 3.2.2.

3.3.3 Equipment Required

The equipment required is generally the same as for the Camera Fly-Over Method, Section 3.2.3, except as follows:

(1) The precision aerial camera with calibrated focal length required by Camera Fly-Over Method is replaced by a conventional camera or visual sighting. Size of the camera is unimportant. A 35 mm camera is convenient since a large number of photos may be obtained on a single roll. A photo record is much preferred over a visual sighting through the reference grid.

(2) Voice Communication Equipment: Tower based radio equipment will be used to communicate with the aircraft under test. Frequency must be compatible with that used by the aircraft. However, in some cases alternate communication may be arranged.

3.3.4 Ground Environment

Same as for Camera Fly-Over Method (see Section 3.2.4).

3.3.5 Personnel Required

Same as for Camera Fly-Over Method (see Section 3.2.5).

3.3.6 Summary of the Method

Advantages

1) Good accuracy.
2) Requires only test aircraft be flown.
3) Results can be used to 20,000 feet altitude and Mach number to 0.6.

Disadvantages

1) Flight close to ground may restrict upper speed limit.
2) Higher turbulence usually present when compared to higher altitude test methods.
3) Slow data collection rate (8 to 15 points/hr, Table VI).
4) Requires a 3-man test crew, usually.
5) Results should not be used to predict performance above 20,000 feet altitude or Mach number greater than 0.6.
6) If a camera is used, test results are not available until the film is developed.

3.4 PACER AIRCRAFT CALIBRATION METHOD

3.4.1 General Description of the Method

In this method the pressure altitude of the test aircraft is measured while flying in close formation with a calibrated aircraft or pacer. Both aircraft contain calibrated pressure instruments. While flying in close formation at the same altitude and about one wing span apart (between wing tips) pressure data is recorded in each aircraft. The pacer aircraft shall have a known pressure calibration as a function of airspeed and Mach number. Using this calibration and the difference in pressure between the two aircraft, the pressure error of the test aircraft may be computed.

This method should only be attempted in smooth air with constant power-setting unaccelerated flight. The operation range for the pacer and test aircraft must be compatible. It is recommended that flights be conducted over water or flat uniform terrain whenever possible. Because of the close proximity of the two aircraft during flight, it is recommended that an experienced test pilot be used in the pacer aircraft. It is recommended that pacer flights be performed at altitudes of 5000 feet and above. Tests may be conducted at any operational altitudes and Mach numbers compatible with the aircraft; hence, this method is not speed and altitude limited. Calibrations at 10,000 foot intervals are usually sufficient to define the test aircraft static pressure error as a function

of Mach number, altitude, and angle of attack.

In the pacer aircraft calibration method, it is required that the reference or pacer aircraft have a static pressure system with known, repeatable, and preferably small position error. This can be accomplished by utilizing a long nose boom such that the static ports are placed approximately one fuselage diameter forward of the nose of the aircraft. In addition, it is required that a well-designed pitot-static tube be utilized which is in itself insensitive to Mach number and angle of attack. An example of such a device is the MA-1 pitot-static tube (Figure 2.6) manufactured to Specification MIL-P-2563B (USAF). In addition to having a small static position error, this error must be pre-calibrated using one or more flight test calibration methods. Since the pacer aircraft is looked upon as a standard, it is required that extensive repeat calibration be performed periodically to insure the reliability of the pacer has been maintained.

Although the pacer-type calibration is well established and has been used extensively for years, the calibration of both pacer and test aircraft must be done with utmost care. In many cases, uncertainty in the calibration of the pacer caused by multiplicity of static pressure readings may seriously alter over-all pressure accuracy, (Reference 16). Of primary importance to the accuracy of this method is the type of pressure instruments utilized.

3.4.2 Accuracies Expected

The calibration accuracy of the pacer aircraft calibration method was analyzed in detail (Reference 16). Analysis assumed the following:

(1) Calibration of the pacer reference aircraft is accomplished at sea level using camera fly-over or similar methods.

(2) Calibration of the test aircraft is accomplished at altitude using fly-by or pacer techniques. Both the test aircraft and the pacer aircraft use either a calibrated precision altimeter or a static port calibrator. Results of an error analysis (Reference 16) are tabulated in Table VIII.

TABLE VIII

PROBABLE CALIBRATION ACCURACY AT ALTITUDE
USING PACER AIRCRAFT CALIBRATION METHODS

Altitude (Feet)	ΔH_1, Feet (±)	ΔH_2, Feet (±)
0	17	5
10,000	48	25
20,000	61	26
30,000	76	28
40,000	92	31
50,000	108	40
60,000	125	36
70,000	140	48
80,000	160	70

NOTE: ΔH_1 = Altitude error using full range precision altimeter.
ΔH_2 = Altitude error using static port calibrators for pacer calibration method at altitude.

Above 50,000 feet, sensitivity of calibration is doubled to reduce calibration errors. Accuracy shown in Table VIII can be realized if no large errors exist in the data measuring process. It is essential that three data points be obtained at each test condition.

3.4.3 Equipment Required

The following is a listing of general equipment needed for pacer aircraft calibration methods:

(1) Pacer Aircraft: The aircraft should be comparable to speed and altitude capabilities of the aircraft to be tested. It should be equipped with nose boom and pitot-static tube proven insensitive to Mach number and angle of attack, see Section 3.4.1. In lieu of or in addition to nose boom installation, pacer aircraft could be equipped with calibrated trailing cone assembly. Prior to use, the aircraft shall have been

calibrated by one or more flight test calibration methods.

(2) Static Pressure Port Calibrator: Typical static pressure port calibrators are specified in Appendix A. Two are required, One is installed in the pacer aircraft and one is installed in the test aircraft. As an alternate, a calibrated precision altimeter (Item 5) may be used in each aircraft. Less accuracy will be obtained as shown in Table VIII.

(3) Pilot's Meter: The pilot's meter, usually furnished with static port calibrator, should be installed on the pilot's instrument panel on both the test and pacer aircraft. The needle indicates pressure differential at the static port calibrator, between the reference pressure and the static system pressure during the flight. If static port calibrator is not used, the pilot's meter is not required.

(4) Air Speed Indicators: Precision airspeed indicator with a certified scale error correction and repeatability accuracy of ± 2.5 knots is required for the pacer and test aircraft.

(5) Altimeter: A calibrated altimeter is required in both the pacer and test aircraft at the flight observer's station.

(6) Voice Communication Equipment: Radio voice communication is needed between the two flight observers on each aircraft and the pilots of each aircraft.

3.4.4 Ground and Atmospheric Environment

The requirements for ground and atmospheric environment during pacer calibration are simple. For aircraft limited to flight altitudes of 20,000 feet or less and Mach numbers of 0.6 or less, calibration at any convenient altitude is sufficient. For aircraft normally flying above 20,000 feet, 10,000 feet increments are sufficient. Flights should be conducted above open and flat terrain or water to avoid ground induced turbulence and danger that occurs in mountainous regions. Flights over areas of heavy population should be avoided. Normal communication with ground base operations should be provided.

3.4.5 Personnel Required

General Engineer.
Qualified Flight Observer for each aircraft.
General Pilot (Test Aircraft).
Test Pilot (Pacer Aircraft).

3.4.6 Summary of the Method

Advantages

1) Tests can be performed at all speeds and altitudes.
2) Lower atmospheric turbulence at altitude.
3) One pacer aircraft may be used to calibrate many test aircraft.

Disadvantages

1) Requires two aircraft be flown.
2) Requires a four-man test crew usually.
3) Moderate data collection rate (20 points/hr, Table VI).
4) Requires pacer aircraft of known calibration.

3.5 RADAR TRACKING CALIBRATION METHOD

3.5.1 General Description of the Method

In this method the geometric altitude of the test aircraft is determined by ground based tracking equipment. The method is usually utilized at altitudes of 5,000 feet and above. The method requires the use of calibrated pressure instruments in the test aircraft to determine atmospheric pressure at altitudes above the radar. The test aircraft must be previously calibrated in at least one condition (such as at a given indicated airspeed) and that this or other calibrated conditions be utilized in the calibration of pressure versus elevation above the radar. After the calibration of the space is performed by the test aircraft operating in the reference or previously calibrated mode, the aircraft is then flown through the test zone at various Mach numbers. As the position error of the aircraft changes with Mach number and/or angle of attack, the aircraft will increase or decrease altitude to maintain constant indicated

altitude. Difference in altitude between the reference and test condition converted to pressure, plus the position error at the reference condition then equals the pressure error at the test conditions.

Several ground base instrumentation type radar installations are located in the United States and operated by the U. S. Government. It appears that these sites could be used for future calibration work on high-performance aircraft if desired. More details on radar tracking calibration method at altitude are contained in Section 6.

This method should only be attempted in smooth air with constant-power-setting unaccelerated flight. Flights should be conducted over the safe operational range of the aircraft as obtained from the aircraft operational manuals. Flights must be conducted adjacent to the radar installation, but flights directly above the radar should be avoided. It will be necessary to correlate the flight program with radar operating personnel and arrange for radio communication with the radar site.

Since the radar method is not speed nor altitude limited, flight tests may be conducted at any operational altitude, indicated airspeed or Mach number. Calibrations at 10,000 foot altitude intervals are usually sufficient to define the aircraft static pressure error.

3.5.2 Expected Accuracy

Utilizing static port calibrator type instrumentation in the test aircraft and accurate ground based precision or instrumentation type radar or photo-theodolite equipment, accuracies on the order of those listed in Table IX can be expected, (Reference 16).

TABLE IX

PREDICTED ACCURACY OF INFLIGHT CALIBRATION
BY RADAR TRACKING CALIBRATION METHODS

Altitude (Feet)	ΔH_1, Feet (±)	ΔH_2, Feet (±)
10,000	38	16
20,000	55	20
30,000	72	24
40,000	89	30
50,000	107	28
60,000	124	36
70,000	141	49
80,000	159	72

NOTE: ΔH_1 = Altitude error using full range precision altimeter.
ΔH_2 = Altitude error using static port calibrator.

In the altitude range from 50,000 feet to 80,000 feet a pressure gage with twice the sensitivity is utilized for calibrator.

3.5.3 Equipment Required

(1) Radar Installation: A mono-pulse AN/FPS-16 instrumentation type radar or equivalent is recommended. Most of the installations are owned and operated by the U. S. Government. Further information regarding location and accuracy of these units is presented in Section 6.

(2) Static Port Calibrator: This device is installed at the observer's station in the test aircraft. An example of a static port calibrator is described in Appendix A. As an alternate, a calibrated precision altimeter may be used in the test aircraft (Item 5). Less accuracy will be obtained as shown in Table IX.

(3) Pilot's Meter: This unit is installed for reference on instrument panel in the pilot's field of vision. This device is usually included with the static port calibrator.

(4) Airspeed Indicator: A precision airspeed indicator with certified scale error correction and repeatability accuracy of ± 2.5 knots is to be installed at flight observer's station. The indicator shall be connected to the aircraft pitot system and to the static system to be calibrated.

(5) Altimeter: A calibrated altimeter is installed at the flight observer's station. The altimeter shall be connected to the static system to be calibrated.

(6) Voice Communication Equipment: Radio voice communication is needed between the aircraft's pilot and flight observer and the ground control radar.

More details regarding possible additional equipment for installation on aircraft is contained in Section 6.

3.5.4 Ground and Atmospheric Environment

Ground environment is relatively fixed by the location of the radar site. Some choice of ground environment is possible by conducting flight tests at a particular region from the radar site. In general, it is best to select a location which is remote from populated areas and commercial air lanes. It is necessary that the flight scheduling be preplanned with the radar installation personnel. It is expected that in the future if considerable use is made of ground base radar installations, standard procedures will be established regarding requesting these services from Government owned and operated facilities.

For aircraft limited to flight altitudes of 20,000 feet or less and Mach numbers of 0.6 or less, calibration at any convenient altitude is sufficient. For aircraft normally flying above 20,000 feet, calibration at 10,000 foot increments is recommended.

3.5.5 Personnel Required

General Engineer.
Qualified Flight Observer.
General Pilot.

3.5.6 Summary of the Method

Advantages

1) Tests can be performed at all speeds and altitudes.
2) Lower atmospheric turbulence at altitude.
3) Requires only one aircraft be flown.

Disadvantages

1) Requires that calibration be performed at the radar site.
2) Scheduling and planning must be arranged with radar installation.

3.6 TRAILING CONE CALIBRATION METHOD

3.6.1 General Description of the Method

A standard method of determining the position error for low spe aircraft is to measure a nearly true static pressure from a trailing bomb or probe. All of the trailing devices of this type are heavy, weighing up to 80 pounds; therefore, offer potential danger to the aircraft in flight and to ground installations. This probe is stabilized by fins to maintain the device at approximately 0° angle of attack. The probe is generally suspended from below the aircraft by a cable. Pressure is transmitted to the aircraft through a tube. The maximum speeds for calibration by this method has been established at approximately 275 miles per hour. Special trailing devices have been used up to Mach number 0.9.

Recently Douglas Aircraft Company Flight Test Department, the Federal Aviation Agency and others have done considerable development and flight testing in lightweight cone configurations. Some information is available in printed literature (References 36, 38, 39 and 40). It is expected that several more reports will be available soon. Results available so far

indicate calibration can be performed with good accuracy. Preliminary data indicates that trailing the cone at a distance of one wing span aft of the aircraft will be sufficient to provide good accuracy. In some cases, closer spacing was utilized.

The advantages of using a trailing cone configuration are immediately apparent in that the position error may be determined as a direct measurement utilizing a differential pressure gage between the pressure ports to be calibrated and the trailing cone. Since the trailing cone may have a small pressure error, it may be necessary to apply a correction to the pressure difference. Using the trailing cone, only one aircraft, namely the test aircraft, is involved. The combination can be flown at all altitudes and hopefully at all Mach numbers, even supersonic. Limitation with ground base facilities is minimized. The use of a lightweight trailing cone appears to overcome all serious deficiencies of the trail probe method.

The method appears particularly well suited to propeller driven aircraft and jet aircraft with wing mounted engines. Satisfactory installations of the cone to aircraft with jet engines within or adjacent to the aft end of the fuselage may be more difficult. Due to long pressure tubing and long time constant (3 to 15 seconds) in establishing the pressure between probe and recording instrument point, only stabilized, constant power setting, level flight conditions should be flown. Calibrating in smooth air is essential.

3.6.2 Accuracy Expected

Reports available to date (References 36, 38, 39, and 40) and other information indicates that trailing cone configurations generally have a small static pressure error. This error is a function of (1) the trailing cone configuration, (2) the mounting location of the tube on the aircraft, (3) the distance aft of the aircraft at which the cone is trailed, and (4) the degree of turbulence at the trailing cone position.

From the above discussion, it is recommended that each trailing cone installation be flight calibrated over the airspeed range that the device is to be used on a particular type

aircraft. The method of calibration should be the same as for any installation, i.e., camera fly-over method, pacer method, or radar tracking method. The calibration accuracy of the cone installation will be a function of the calibration method (Tables VII, VIII, and IX).

When the calibrated trailing cone is used as a calibrating device, a sensitive differential pressure gage should be installed between the aircraft static ports and the trailing cone static ports. This device should have resolution on the order of one foot of altitude at sea level and repeatability (including hysteresis) of 5 feet of altitude at sea level. Typical accuracy of a static port calibrator or limited range pressure gage is shown in Curve (3), Figure 2.17. When the probable calibration accuracies using the pacer method at altitude are combined with the pressure gage accuracies, Curve (3), Figure 2.17, the results are as shown in Table X.

If the basic cone calibration is performed by the radar tracking method, results comparable to those shown in Table X should be obtained. This is because the accuracies given in Tables VIII and IX are similar.

TABLE X

PROBABLE CALIBRATION ACCURACY AT ALTITUDE USING (1) PACER AIRCRAFT TO CALIBRATE THE TRAILING CONE INSTALLATION, AND (2) TRAILING CONE TO CALIBRATE AIRCRAFT SYSTEMS

Altitude, Feet	ΔH_2, Feet (±)
0	8
10,000	26
20,000	27
30,000	29
40,000	32
50,000	42
60,000	37
70,000	50
80,000	73

NOTE: ΔH_2 included altitude error using static port calibrator in pacer calibration at altitude. Above 50,000 feet, sensitivity of both calibrators is doubled to reduce calibration errors.

3.5.4 Equipment Required

The following is a listing of requirements needed for trailing cone method:

1) Trail Cone Assembly: An approved trailing cone assembly should be utilized. The configuration will show small static pressure error and should be aerodynamically stable over as wide a range of flight conditions as possible. Unit must be able to withstand aerodynamic loads over a flight range of the aircraft to be tested.

A design developed by the Federal Aviation Agency (References 36, 38, 39, and 40) consists of the following:

a) A light weight fiber glass conical shell with perforated surface and 8-inch base diameter. For aircraft limited to 200 knots indicated airspeed and below, cone base diameter of 10 or 12 inches may prove more satisfactory.

b) Approximately 60 inches of 1/4 inch O.D. nylon tubing is attached to the nose of the cone. The attachment of tube to cone is accomplished by use of a thrust bearing such that axial spin of the cone is not transmitted to the nylon tubing.

c) Approximately 24 inches of 1/4 inch O.D. steel tubing is "spliced" onto the plastic tube. This tube section contains multiple small holes drilled around the circumference of the tube over the center 6 inches of the tube.

d) Up to 150 additional feet of plastic tubing are run between the metal tube section and the attachment point on the aircraft.

e) Up to 150 feet of steel wire or cable which run from the cone thrust bearing to the aircraft attachment point. This wire must be of sufficient diameter to sustain the cone drag load during flight.

f) A method of attachment of the plastic tube and steel wire to the aircraft must be provided. The method of attachment and location of attachment will vary depending primarily on aircraft geometry as discussed in the next paragraphs.

The location of the attachment and method of attachment of the trailing cone will vary considerably from aircraft to aircraft. The simplest installation is to attach at the aft end of the fuselage, probably below the horizontal stabilizer. It is further simplified if the use of a reel is not needed and the aircraft takes off with cone extended, (References 38 and 40). It is also practical to land with cone extended. If damaged on landing, the cone and attachments can easily be replaced before the next flight. Attachment to aft end of fuselage below horizontal stabilizer is recommended for all propeller driven aircraft and jet aircraft with engines located in the wing

For aircraft with jet engines located at, within, or adjacent to the aft end of the fuselage, the top of the vertical fin is probably the only practical mounting location. Great simplification occurs if the cone assembly can be trailed at full extension during take-off. The use of an electric reel requires more extensive modification of the aircraft. The extension of the cone using aerodynamic loading increases complexity and decreases probability of a successful calibration.

2) Differential Pressure Gage: An accurate limited range differential pressure gage must be installed, between the static pressure installation and the trailing cone at the flight observer's station. Details on a typical unit are included in Section 3 of Appendix A.

3) Airspeed Indicator: A precision airspeed indicator shall be installed at the flight observer's station. The indicator must have a certified scale error correction and a repeatability of ± 2.5 knots. The indicator shall be connected to the aircraft pitot system and to the static system to be calibrated.

4) Altimeter: A calibrated altimeter shall be installed at the flight observer's station. The altimeter shall be connected to the static system to be calibrated.

3.6.4 Ground and Atmospheric Environment

The requirements for ground and atmospheric environment during trailing cone calibration are simple. For aircraft with altitude limit of 20,000 feet or less and maximum flight Mach numbers of 0.6 or less, calibration at any convenient altitude is sufficient. For aircraft normally flying above 20,000 feet, calibration at 10,000 feet increments are recommended. Flights should be conducted above open and flat terrain or water. Flights should only be conducted in areas of unlimited horizontal visibility and in non-turbulent air. Flights over heavily populated areas should be avoided. Normal communication with ground based operations should be provided. Filing and use of standard and approved flight procedures is required.

3.6.5 Personnel Re[illegible]ed

General Engineer.
Qualified Observer.
General Pilot.

3.6.6 Summary of the Method

Advantages

1) Requires only the test aircraft be flown.
2) Tests can be performed at all speeds and altitudes.
3) Fast data collection rate.
4) Requires minimum test crew (two men).
5) Lower atmospheric turbulence at altitude.

Disadvantages

1) Requires installation of trailing cone to the test aircraft.
2) Requires calibration of the trailing cone on the test aircraft type.

SECTION 4

CAMERA FLY-OVER CALIBRATION METHOD

1. INTRODUCTION

In the Camera Fly-Over method of flight calibration, the "tape-line" or absolute altitude of low flying aircraft is accurately determined by photographing the aircraft from the ground with a high resolution camera. True static pressure at the aircraft's altitude is computed from the tape-line altitude and measurements of the absolute barometric pre[illegible]re and the static temperature at the camera location. The s[illegible]tic pressure position error is determined by measuring the difference between static pressure measured on the aircraft and barometric pressure at the camera location. Corrections are made for the difference between barometric pressure and true static pressure at the aircraft's altitude. A typical flight pattern for the Camera Fly-Over method is included on Figure 4.1.

The Camera-Fly-Over method is a variation of the Tower Fly-By method of altitude calibration (References 37, 42, 43, and 44), where the aircraft is flown past a tower or a tall building. A typical flight pattern for Tower-Fly-By method is shown on Figure 4.2. The aircraft is sighted through a reference grid arrangement, at or near the tower, by a camera or eyepiece located in the tower. The height of the aircraft above or below a fixed point in the tower is determined by triangulation. The horizontal distance of the aircraft from the tower must be accurately known. This distance is usually determined by having the aircraft fly down the centerline of a runway located in front of the tower. Deviations of the aircraft from this centerline can be corrected by using two instrumented towers, one on each side of the runway (Reference 44).

The Camera Fly-Over method is described in detail in this section. However, the following procedures can be easily adapted to the Tower Fly-By technique if facilities are available and have accuracies comparable to those described below for the Camera Fly-Over method. It is recommended that if Tower-Fly-Over facilities are not already available, the Camera Fly-Over method be used.

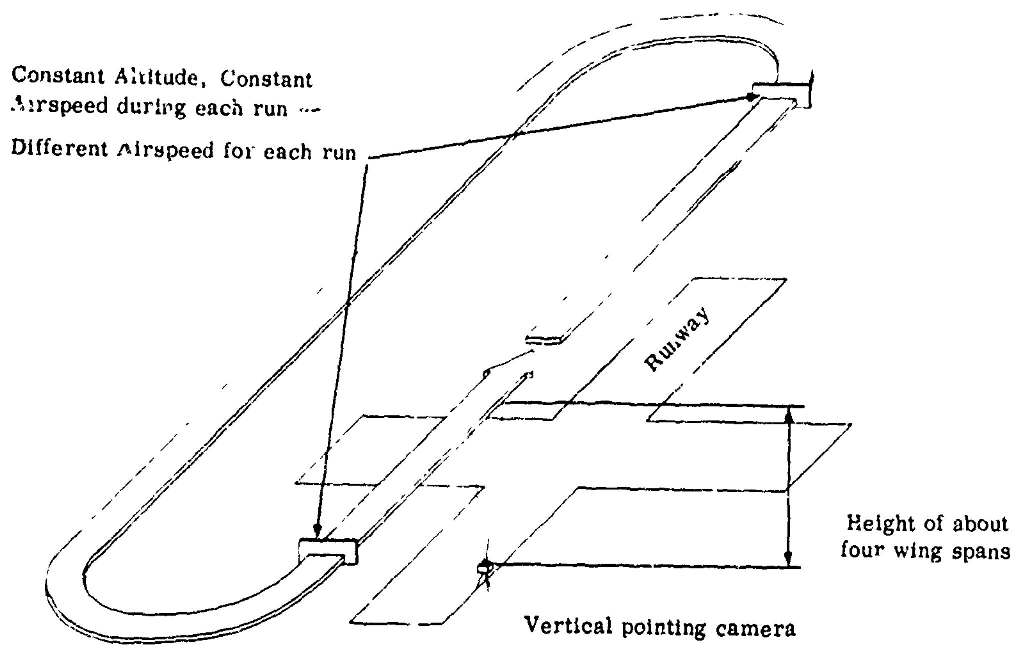


Figure 4.1

Typical Flight Path for Camera Fly-Over Calibration Procedure

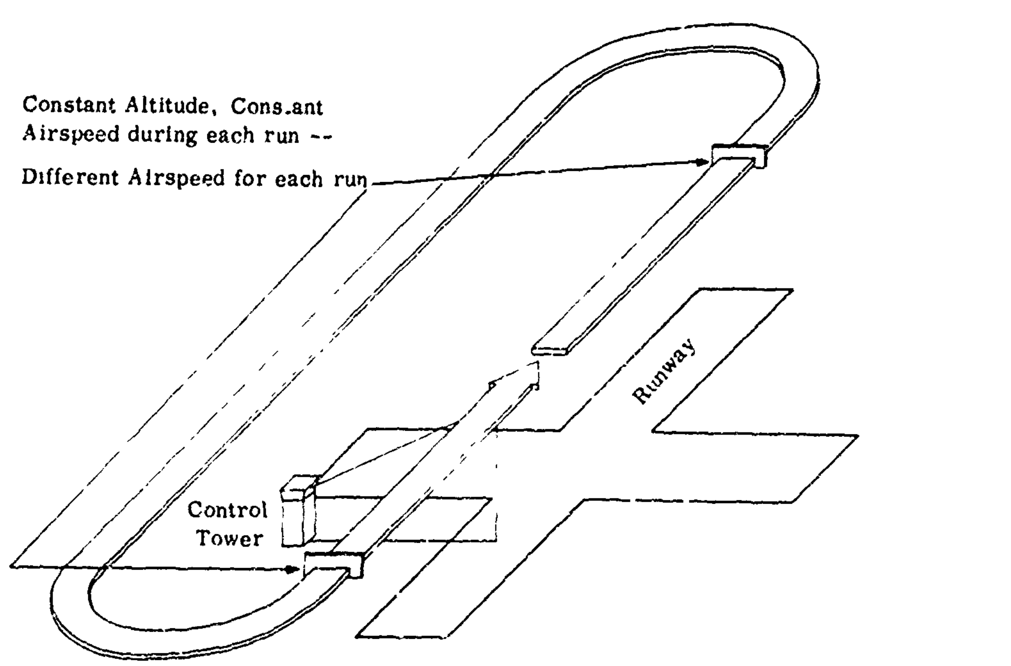


Figure 4.2

Typical Aircraft Flight Path for Tower Fly-By Flight Calibration

Two procedures for "Camera Fly-Over" calibration are included in this section. The first procedure uses a calibrated full range altimeter in the test aircraft to determine pressure altitude and can be used for low speed aircraft (Mach number less than 0.6) with limited altitude (less than 20,000 feet) capabilities. The second procedure uses a limited range differential pressure instrument, with sealed pressure sample, i.e., a static port calibrator, in the test aircraft to determine the difference between static pressure measured on the aircraft and barometric pressure at the camera location. The differential pressure instrument provides the increased accuracy needed for calibration of aircraft with high speed and altitude capabilities. Equipment required and methods of obtaining data for each procedure are described in the following sections.

4.2 GROUND EQUIPMENT

The ground camera test site should be located on the right edge of an airport runway and near the threshold or front end of the runway. Selection of the runway will depend on the wind direction. The runway edge is used as a reference by the pilot when he aligns the aircraft to fly over the camera. The runway should be long enough so that the pilot can maintain this reference until he has passed over the camera. (If a long auxiliary runway not used by regular traffic can be selected, a camera site about 1/3 of the distance down the runway and on an unused exit lane would be desirable). The camera should be on or very near a run-up pad on which the test aircraft can be parked for short periods of time before and after the tests.

At the camera test site, the following equipment is required. One trained technician or engineer is needed to operate the equipment. In certain instances it might be helpful to have another observer on the ground to guide the pilot over the camera.

(1) Camera: A precision camera of the type used for aerial reconnaissance and mapping should be used. A manually operated single exposure camera is preferred. Two cameras of this type that have been proven acceptable are the F-8 (Reference 24) and the K-24 (Reference 25). Another acceptable single-exposure camera is the T-11 (Reference 26). The T-11 is more elaborate than the F-8 or K-24 and requires 24 volt DC electric power at the camera site.

The focal length (f) of the lens and the width of the film should be selected to provide a field of view of approximately 40° and an accuracy of better than ± 1 foot in determining the height of an aircraft above the camera. As an example, if an aircraft with 70-foot wing span is 400 feet above the camera and the camera focal length is 7.14 inches, the film image of the wing span is 1.25 inch; an overall measurement accuracy of this image of about 0.003 inch would be required to determine the 400 feet elevation within ± 1 foot. For small image sizes, magnification might be necessary to obtain the desired accuracy.

The camera is rigidly mounted on a heavy duty tri-pod with its principle axis pointed vertically upward. Leveling equipment is needed to provide the proper orientation.

The camera should be equipped with a sighting device to allow the operator to photograph when the aircraft is directly over the camera.

(2) Voice Communication Equipment: The ground operator will need a mobile, battery operated, transceiver to communicate with the aircraft under test. Frequency range must be compatible with that used by aircraft. However, in some instances alternate communications can be arranged.

(3) Barometer: A precision aneroid barometer or a precision altimeter is required to record barometric pressure and barometric pressure changes at the camera location. The unit selected should have good stability and repeatability, low hysteresis, and small temperature dependency over a range that covers the extremes in test site barometric pressure. A precision altimeter will give the required accuracy for the "Full Range Altimeter" camera fly-over calibration procedure. A precision aneroid barometer with 0.001 inch Hg divisions is required to obtain the necessary accuracy for the "Static Port Calibrator" camera fly-over procedure.

(4) Thermometer: A laboratory precision grade thermometer will be required to monitor temperature at the camera location. The scale should be in 1°F or 1°R increments for ease in reading and in data reduction.

(5) Instrument Shelter: An instrument shelter is needed to protect the altimeter and thermometer from direct sunlight and strong winds. It should be constructed of wood and louvered to allow free circulation of air around the instruments. The shelter

is placed in close proximity to the camera, and the instruments in the shelter are located at the same elevation as the lens on the camera.

(6) Clock: A clock or watch is needed for time coordination of the test data.

4.3 AIRBORNE EQUIPMENT

Equipment mounted in the test aircraft is listed below for the two calibration procedures described in this section. The equipment is monitored and data is recorded by a qualified flight observer, or the pilot in the case of a single place aircraft.

4.3.1 "Full Range Altimeter" Procedure

(1) Altimeter: A calibrated precision altimeter is installed in the test aircraft. It is selected to have good stability and repeatability, low hysteresis, and small temperature dependency. The unit shall have been calibrated within the preceding 10 days and have a certified corrected scale error and repeatability of ± 0.010 inches Hg (ΔH_{s1} = ± 10 feet). (The barometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg (References 14 and 41). A recommended complete calibration procedure is included in Appendix B. The altimeter errors must be small and well defined over a very limited altitude band. Calibration increments of 100 feet pressure altitude are used over an operating range of about -1000 feet to +3000 feet in pressure altitude from the ground test site elevation. A calibration chart of altimeter instrument correction (ΔH_{ic}) vs uncorrected altimeter reading (H_i) is needed with the altimeter for use in data reduction. THE CALIBRATION OF SPECIAL ALTIMETERS SHALL BE AT AN ALTIMETER SETTING OF 29.92 (Inches Hg).

(2) Airspeed Indicator: A precision airspeed indicator with a certified corrected scale error and repeatability accuracy of ± 2.5 knots is needed to determine airspeed of the test aircraft. The indicator is to be selected for low hysteresis and good stability and repeatability and certified within the preceding 30 days.

The manometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg. A calibration chart of airspeed indicator instrument correction (ΔV_{ic}) vs indicated airspeed (V_i) is needed with the airspeed indicator for use in data reduction.

4.3.2 "Static Port Calibrator" Procedure

(1) Calibrator: A static port calibrator is installed in the test aircraft. Description of a typical calibrator is given in Section 2 of Appendix A. The unit shall have been calibrated within the preceding 10 days. The calibrator's instruction manual should be reviewed thoroughly before the unit is used.

Calibrators usually have a visual meter for use by the flight observer. This meter can be used to measure accurately pressure differential during low-speed, low-altitude camera fly-over calibration. However, full scale range of the meter is usually small, e.g., ΔH_{si} = ± 200 feet. Reduced sensitivity for the meter will decrease the accuracy of the meter and should be used only for calibration of aircraft with low-speed and low altitude capabilities. A description of a typical meter is included in Section 2 of Appendix A.

(2) Recording Oscillograph: For calibration of high performance aircraft, an observer's meter on the calibrator should be used only as a secondary reading. An airborne recording instrument is then required to measure accurately pressure differential from the static port calibrator during the Camera Fly-Over calibration. A 12" recording oscillograph is recommended. At least 10 inches of the 12-inch trace width should represent the differential pressure range of the calibrator. Traces of compressible dynamic pressure (q_{cm}) and absolute static pressure (p_m) from multi-sweep pressure transducers of the SFIM type (Ref. 27), or equivalent, should also be included. Airspeed and altitude are determined from q_{cm} and p_m, respectively. The "airspeed" and "altitude" transducers give a continuous trace of these parameters and are used to detect variations in airspeed and altitude during a calibration pass over the camera. Large variations could introduce pressure lag errors and cause rejection of data for a pass. The airspeed transducer is also used to obtain the compressible dynamic pressure (q_{cm}), used to form the ratio $\Delta p/q_{cm}$ during data reduction.

A time recording is desirable on the galvanometer trace; although if not available. the flight observer can mark the film with a spare trace channel and record the film footage number on voice command from the ground camera operator.

Angle of attack, and possibly angle of sideslip, traces and a total temperature or free air temperature trace might also be desirable for certain high performance aircraft. Air temperature is a refinement which enables detection of a non-standard temperature lapse rate at the fly-over altitude.

The recording oscillograph is laboratory calibrated at the same time as the static port calibrator to determine conversion constants and any non-linearity of the trace signals.

(3) Airspeed Indicator: An alternate to the airspeed and altimeter transducers in the recording oscillograph would be to install, in the test aircraft, a calibrated airspeed indicator of the type specified in Section 4.3.1. However, the manual reading of this indicator could prove undesirable for high subsonic Mach number calibration. The continuous trace feature, to detect variations in airspeed and altitude, is also omitted.

(4) Pilot's Meter: A meter is usually provided to give the pilot an indication of pressure differential of the static port calibrator. The meter is calibrated for a small range of pressure differential. The meter is needed for altitude calibration of an aircraft, but is not used directly by the pilot for Camera Fly-Over calibration. Installation of this meter is not required if the only method to be flown is Camera Fly-Over. However, if altitude testing follows, it might be desirable to install the pilot's meter at this time. Description of a typical meter is included in Section 2 of Appendix A.

4.4 CAMERA CALIBRATION

A recommended procedure for accurately determining Focal Length of the camera is to photograph distances between parallel rods, at a known distance from the camera. The following equation is used.

$$f = \frac{L_i \, (d)}{L} \qquad (4.1)$$

where, f = Focal Length, in inches.

L = Actual taped length between two parallel rods, in feet. Measured in a plane parallel to the focal plane of the camera.

d = Distance from the camera lens to the midpoint between the two rods, in feet. Measured on or parallel to the principal axis of the camera.

L_i = Film image length between the two rods, in inches.

The parameters are shown in the following sketch, Figure 4.3. The camera is rigidly mounted on a tri-pod with its principal axis horizontal. Leveling equipment is needed for camera alignment. A total of six rods are used as a photographic target. The rods are about 1/2" to 1" in diameter and are placed at even intervals in a plane parallel to the focal plane of the camera. A wire is stretched between the rods at a location that will coincide with the horizontal projection of the camera's principal axis, as shown on the side view on Figure 4.3. The distances between rods are accurately measured with a tape scale. The camera lens is at a known, taped distance "d" from the center of the target segment "c". The distance "d" is measured in a plane parallel to the principal axis of the camera.

The target is photographed at intervals over the entire film area to determine if focal length changes with location on the film. A recommended procedure is included below.

(1) Select "d" at minimum distance for precise image, but not less than 100 feet. Sharp images for infinity focus occur about 250 focal lengths from the camera.

(2) Calculate "L" from Equation 4.1 letting L_i = film height. (For "f" use the nominal focal length specified for the camera).

(3) Divide length "L" of target into five Zones, "a" through "e", equally spaced as shown in Figure 4.3.

(4) Place center of target image at center of camera film; i.e., center of Zone "c" in horizontal (film height) direction with the wire extending between the rods at the center of the film width, center of Zone "4".

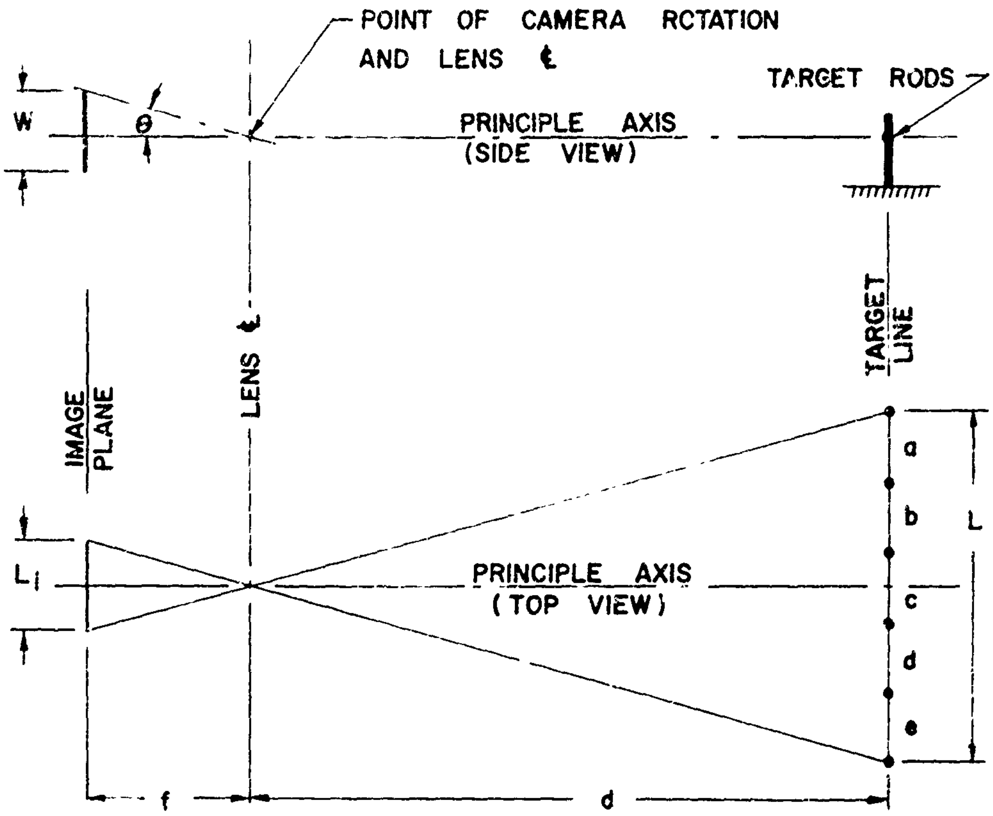


Figure 4.3

Sketch of Parameters for Determination of Camera Focal Length

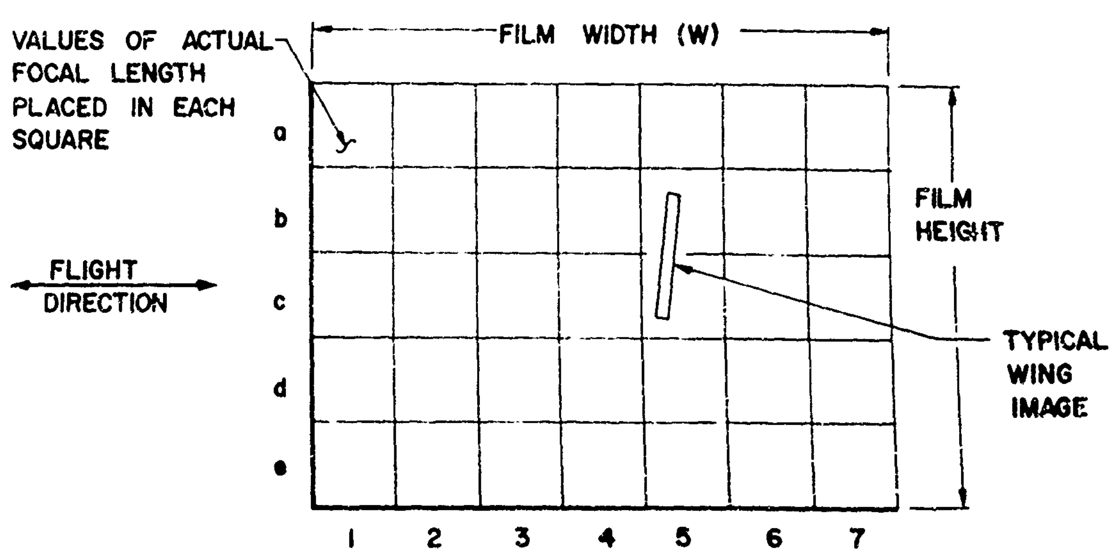


Figure 4.4

Sketch of Transparent Calibration Chart of Actual Focal Length Over Film Area

The zones are identified on Figure 4.4. A ground glass screen can be used for positioning the image.

(5) Photograph target.

(6) Rotate camera up to elevation angle $2\theta/7$. This will place target at center of Zone 3. The angle θ is determined from the equation

$$\tan \theta = w/2f \qquad (4.2)$$

where w is the camera film width*, in inches, and f is the nominal focal length, in inches.

(7) Photograph target.

(8) Repeat steps (6) and (7) rotating the camera to positive elevation angles $4\theta/7$ and $6\theta/7$ (centers of Zones 2 and 1, respectively), and to negative elevation angles $2\theta/7$, $4\theta/7$ and $6\theta/7$ (centers of Zones 5, 6, and 7, respectively).

(9) Develop film.

(10) Measure length images (L_i) of each length segment (L), "a" through "e", on each frame (35 readings) and calculate the focal length "f" from Equation 4.3 for each reading.

$$f = \frac{L_i\,(d)}{L \cos \theta_1} \qquad (4.3)$$

The angle θ_i is the camera rotation angle, i.e., 0°, $2\theta/7$, $4\theta/7$, or $6\theta/7$.

(11) On transparent grid, similar to sketch shown on Figure 4.4, enter the 35 calculated "f" values in squares provided.

An accuracy of <u>0.005 inch</u> is needed in the determination of focal length. If this accuracy can not be maintained for a single value of "f" over the film area, the transparent calibration chart, Figure 4.4 will be needed for reduction of the flight test data. The chart can be superimposed on each film frame during data reduction to determine the actual focal length for the aircraft's wing image location on the film. A typical wing image is

* The width direction should be chosen for flight direction.

shown in Figure 4.4. For the position shown, the effective focal length will be:

$$f = (f_{b5} + f_{c5})/2$$

or $$f = \text{(reading in square b5 + reading in square c5)}/2.$$

Before and after the flight tests, it might be desirable to have test frames at the start and end of the film roll. The test frames can be obtained by photographing a hangar door or similar object of known dimensions. This will give a check on the effective focal length and could be used to correct for any film shrinkage during developing.

Film obtained during flight test should be left in a single roll to allow easy identification of individual frames.

4.5 "FULL RANGE ALTIMETER" TEST PROGRAM

4.5.1 Prior-to-Flight Procedure

The following installations are made prior to the flight test.

(a) The special calibrated altimeter is inserted into the primary static system of the test aircraft. It is permissible to replace the aircraft altimeter with the special altimeter if desired.

(b) The special airspeed indicator is inserted into the primary static system and pitot system of the test aircraft. It is permissible to replace the aircraft's airspeed indicator with the special airspeed indicator if desired. (If the aircraft's regular airspeed indicator meets the requirements of Section 4.3.1, it may be used in lieu of the special airspeed indicator).

(c) After insertion of the altimeter and the airspeed indicator, the pitot and static pressure lines are sealed and pressure checked with an airspeed system field test unit. With the source of vacuum isolated, the maximum allowable leak rate for the complete static pressure system is twenty (20) feet/minute at +3000 feet (calibrated range for altimeter) above the ground test site elevation. With the source of pressure isolated, the

maximum allowable leak rate for the complete pitot pressure system is 5 knots/minute at 200 knots, or at 80% of the maximum range if it is less than 200 knots. (Static pressure applied for either test must not exceed the equivalent altitude limits of -1000 to +3000 feet above the ground test site elevation).

The following measurements are made prior to the flight test. (See Figure 4.5 for diagram showing measurements required).

(a) The height (h_1) of the camera lens above ground at the test site.

(b) The height (h_2) of the aircraft's wing tips above the ground at the run-up pad.

(c) The difference in elevation (h_3) between the run-up pad and the camera test site. This difference can be accurately determined by using a surveyor's level. (Note: It is desirable to place the camera at the side edge of the runway (run-up pad or taxi-way) and as close to the aircraft as possible. If the camera is located near the aircraft and on the run-up pad, the height difference (h_3) will be zero.

(d) The actual wing span (b) of the test aircraft.

4.5.2 Flight Test Coordination and Pilot's Orientation

The flight test observer is responsible for coordination of the flight test program. (If the flight observer is not completely qualified, the flight test engineer must coordinate the program). The observer should be familiar with the operational manual of the aircraft under test. He must brief the pilot and the ground site operator before the flight begins on all applicable parts of the following Section 4.5.3. Paragraph 4(b), which requires level unaccelerated flight while the aircraft is over the camera, is especially important for the pilot to understand. Examples of check lists for the flight test observer, pilot, and ground site operator are given in Sections 4.5.4, 4.5.5, and 4.5.6.

The flight observer also makes out a flight test plan for the pilot and the ground site operator which states each test point required and the sequence of tests. Forms 4-1, 4-2, and 4-3 at the end of this section are examples of data cards which would be prepared by the flight observer.

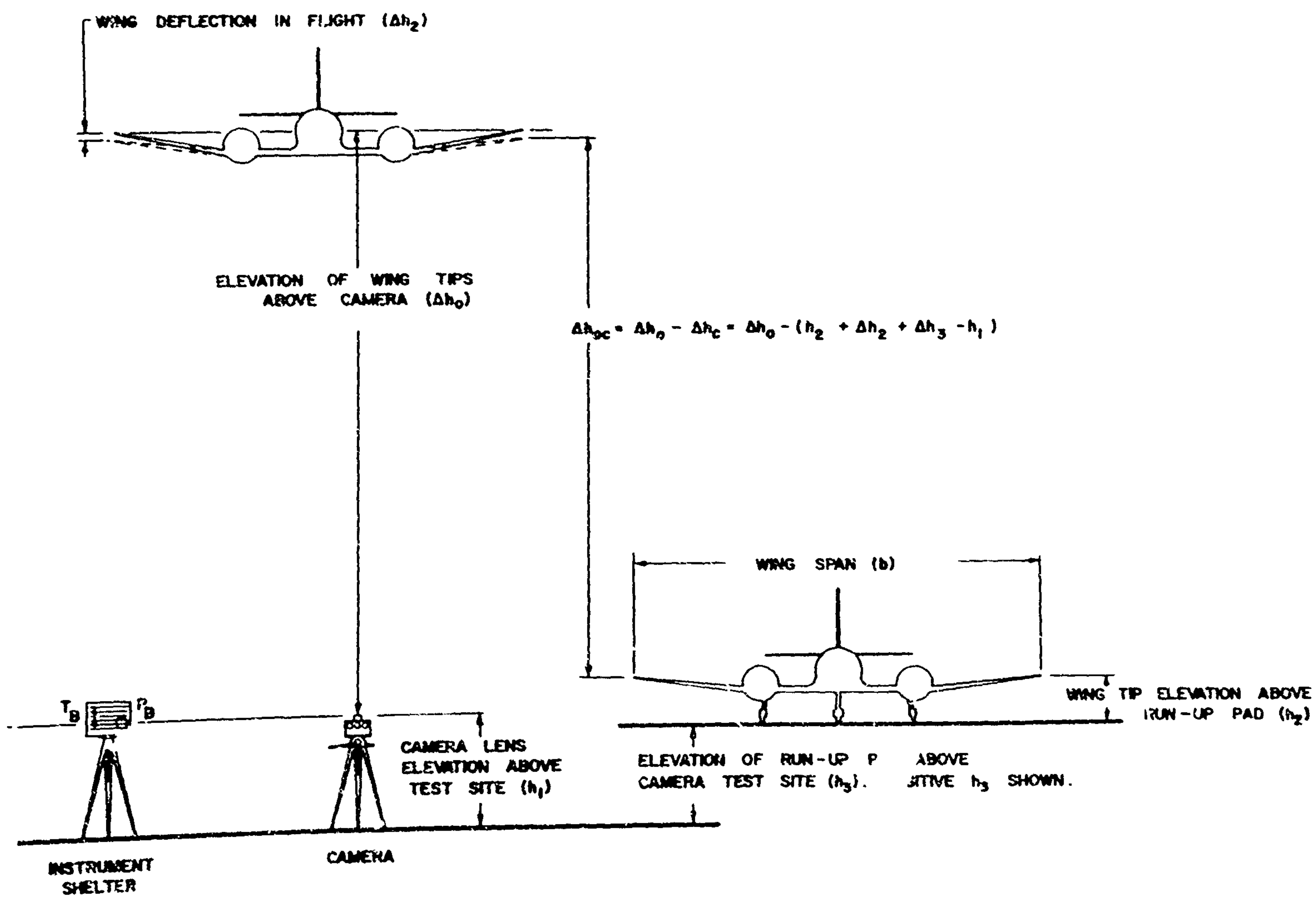


Figure 4.5

Diagram showing measurements required for "Camera Fly-Over" Calibration Method

4.5.3 Flight Test Procedures

(1) A minimum of three and a maximum of six fly-over passes should be made at each reference speed listed below. All passes should be accomplished during a single flight and a minimum of time should elapse between when the aircraft takes off and lands.

(a) Normal landing configuration with gear and flaps extended. (Test at three different speeds which cover the safe operational limits of the aircraft).

(b) Normal approach configuration with gear and flaps extended. (Test at three different speeds which cover the safe operational limits of the aircraft).

(c) Normal approach configuration with gear retracted. (Test at three different speeds which cover the safe operational limits of the aircraft).

(d) Minimum safe speed with gear and flaps retracted.

(e) Maximum safe speed with gear and flaps retracted.

(f) Three different intermediate speeds between minimum and maximum safe speeds with gear and flaps retracted.

The above requirements are applicable for original calibration of the airspeed system following construction or major overhaul or modification to the airframe. Some of the flight conditions (a) through (d) might be redundant for some aircraft and could therefore be eliminated. For a recalibration check of an aircraft previously calibrated (those having calibration cards or graphs for the static pressure system), it should only be necessary to conduct (c), (d) and (e) from above. The flight test observer should review the aircraft's operational manual and test objectives to see if additional test points are necessary.

(2) Immediately preceding the flight tests, the aircraft is taxied to ground run-up pad and faced into the wind. The engines are shut down or idled so as to eliminate air flow over the static pressure sensing ports. The following measurements are made and recorded simultaneously and the time noted.

(a) Special altimeter in test aircraft.

(b) Altimeter at ground test site. (Note: Both altimeter readings are taken after a gentle tapping on the face plate of the instrument. The special altimeters will remain at the altimeter setting of 29.92 at all times).

(e) Temperature at ground test site.

(d) Time.

(3) The aircraft takes off and prepares for the camera fly-over passes. Altitude should not exceed 3000 feet above the ground test site elevation (calibrated range of the test aircraft's special altimeter) at any time during the flight.

(4) The aircraft then flies directly over the camera, using the side edge of the runway for alignment, at the reference speeds noted in Item (1). The following factors are important to the flight test portion of this program.

(a) The nominal height of the aircraft above the test site is four wing spans of the aircraft. (The height of the aircraft above the test site should not exceed 500 feet, nor be greater than six times the wing span of the aircraft. The height of the aircraft above the test site should not be less than two times the wing span of the aircraft).

(b) All test runs over the camera are made in level unaccelerated flight. The aircraft is stabilized on the indicated airspeed and approximate desired altitude prior to reaching the camera site and maintains constant airspeed (constant power setting) and level altitude during the run. Stabilized flight is more important than the exact altitude or airspeed. The aircraft should not be banked during the run. Flights into the wind or downwind are preferable.

(c) The tests should be conducted under non-turbulent atmospheric conditions (smooth air). Consideration should be given to conducting tests in the early part of the day to minimize air turbulence due to solar heating of the terrain.

(d) Due to close proximity of the flights to the ground, necessary approval may be required prior to the flight tests. The approach path of the aircraft should take into account its proximity to any residential area.

(e) With the noted exception of single-place aircraft, all in-flight readings are made and recorded by a qualified observer. A qualified observer is defined as an experienced engineer, pilot, instrument mechanic, or person familiar with the special instruments being recorded, and the procedures described in this section.

(f) Aircraft gross weight should be near nominal throughout the flight tests.

(5) The observer in the test aircraft records the altimeter reading and airspeed reading upon receiving a signal from the ground that the aircraft is within the field of view of the camera. Simultaneously, the ground site operator photographs the aircraft, after which he immediately records the ground altimeter reading and temperature reading. Time of readings is recorded by both the aircraft observer and the ground operator.

(6) At completion of the test flight, the aircraft lands, is taxied to the run-up pad, faced into the wind, and the engine shut down (or idled to prevent disturbance of pressure at the aircraft's static pressure ports). The following measurements are then made and recorded in the same manner as was done prior to the test flights.

(a) Special altimeter in test aircraft.

(b) Altimeter at ground test site.

(c) Temperature at ground test site.

(d) Time.

(7) Data reduction and the determination of the static pressure position error of the aircraft for each of the flight conditions is outlined in detail in Section 8.

4.5.4 Check List for Flight Test Observer

A. Special Airborne Equipment:
   1. Calibrated Precision Altimeter.
   2. Calibrated Airspeed Indicator.

B. Aircraft Installation:
   1. Install Altimeter and Airspeed Indicator.
   2. Leak check pitot and static pressure systems.

C. Prior-to-Flight:
   1. Determine test points required (check aircraft operational manual).
   2. Make provisions to determine gross weight of aircraft.
   3. Fill out data cards and flight test plan (Forms 4-1, 4-2, and 4-3).
   4. Coordinate with pilot and ground observer and have a thorough preflight briefing with both.
   5. If necessary, obtain air traffic or legal approval for tests over residential areas.
   6. Set watch with watches of pilot and camera operator.

D. Flight: (Record at each test point)
   1. Altimeter reading (Altimeter setting at 29.92).
   2. Airspeed indicator reading.
   3. Time.

E. Post Flight:
   1. Gather all data cards.
   2. Reduce data using Forms 8-1 in Section 8.

4.5.5 Check List for Ground Site Camera Operator

A. Ground Equipment:
1. Camera.
2. Voice communication equipment.
3. Precision altimeter.
4. Thermometer.
5. Instrument shelter.
6. Watch.

B. Special Measurements:
1. Calibrate camera focal length.
2. Measure height of camera lens above ground.
3. Measure height of aircraft's wing tips above ground.
4. Measure difference in elevation between run-up pad and camera test site.
5. Measure wing span of aircraft.

C. Prior to Flight:
1. Practice photographing aircraft prior to the flight tests.
2. Preflight briefing with pilot and flight test observer.
3. Review ground site operator's data card (Form 4-3).
4. Shoot test frame at start of film roll.

D. Flight Test: (Record at each test point).
1. Altimeter reading (Altimeter setting at 29.92).
2. Temperature.
3. Film frame number.
4. Time.

E. Post Flight:
1. Shoot test frame at end of film roll.
2. Develop film as a continuous roll.

4.5.6 Check List for Pilot:

1. Pre-flight briefing with flight observer and camera operator.
2. Review pilot's test sequence card (Form 4-1).
3. Altitude should not exceed 3000 feet above the ground test site elevation during entire flight.
4. Use side edge of runway for reference, flying directly over the camera is important.
5. Nominal height of aircraft above test site is four wing spans.
6. Stabilize on approximate airspeed and approximate desired altitude prior to reaching the camera site and maintain constant airspeed (constant power setting) and level altitude during the run.
7. All tests over the camera are made in level unaccelerated flight.
8. The aircraft should not be banked during the run.
9. Conduct tests under non-turbulent atmospheric conditions (smooth air).
10. Flights into the wind or downwind are preferable.

FORM 4-1

PILOT'S TEST SEQUENCE CARD

(Fill In Before Test Begins)

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Pilot:

Test Point	Aircraft Config.	Nominal Altitude (xxx) ft	Nominal Airspeed (xxx) Knots	Remarks
Initial	-----	----	0	Taxi to camera site, face into wind, shut down or idle engine(s)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
FINAL	-----	----	0	Taxi to camera site, face into wind, shut down or idle engine(s).

FORM 4-2

FLIGHT OBSERVER'S DATA CARD

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Data Taken By:

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)			
Test Point	Aircraft Config.	Nominal Altitude	Nominal Airspeed	Altimeter Reading	Airspeed Reading	Time	Remarks
		(xxxx.) ft	(xxx.) knots	(xxxx.) ft	(xxx.) knots		Gross weight =
Initial		----	0		----		
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
FINAL	----	----	0		----		Gross weight =

FORM 4-3

GROUND SITE OPERATOR'S DATA CARD

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Data Taken By:

(FILL IN BEFORE TEST BEGINS)				(RECORD AT EACH TEST POINT)				
Test Point	Aircraft Config.	Nominal Altitude (xxxx.) ft	Nominal Airspeed (xxx.) knots	Altitude Reading (xxxx.) ft	Temp. At Test Site (xx.) °F	Film No.	Time	Remarks
Initial	----	----	0			--		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
FINAL	----	----	0			--		

4.6 STATIC PORT CALIBRATOR TEST PROGRAM

The "Camera Fly-Over" calibration method using the static port calibrator principle is very similar to the full range altimeter method described above in Section 4.5. However, some additional equipment and slightly different procedures and data reduction are used to obtain the improved accuracy over the full range altimeter method. To eliminate any confusion between the two methods, the complete "calibrator" test program is included below. Ground and airborne equipment needed is listed in Section 4.2 and 4.3.2. Camera calibration is explained in Section 4.4. Operating instructions for a typical static port calibrator are presented in Section 2 of Appendix A.

4.6.1 Prior to Flight Proceuures

The following installations are made prior to the flight test.

(a) "T"-shaped pressure fittings are placed in the primary pitot pressure and static pressure lines of the test aircraft. Flexible, non-collapsible tubing is used between each "T" and the calibrator and oscillograph mounting location in the aircraft. The tubing length should be kept as short as possible. The static tubing should have an internal diameter of about 0.305 inch and the pitot tubing should have an internal diameter of about 0.180 inch. The "T" fittings may be made permanent installations on the aircraft and are to be disconnected from the special tubing and capped when not used for calibration flights.

(b) The recording oscillograph is placed at the observer's station in the test aircraft. Altitude and airspeed pressure transducers in the oscillograph are connected to the flexible pitot and static pressure tubings. A "T" is placed in the static pressure line, at the observer's station to allow connection to the calibrator unit.

(c) The static port calibrator is placed at the observer's station and connected to the static pressure line.

(d) After insertion of the calibrator and special altitude and airspeed pressure transducers, the aircraft's primary pitot and static pressure lines are sealed and pressure checked with an airspeed system field check unit. With the source of vacuum isolated, the maximum allowable leak rate for the complete static system over a period of 5 minutes is twenty (20) feet/minute at an initial pressure altitude of 18,000 feet. With the source of pressure isolated, the maximum allowable leak rate for the complete pitot pressure system over a period of 5 minutes is 2 knots/minute at the maximum airspeed attainable with the aircraft.

The following measurements are made prior to the flight test (see Figure 4.5 for diagram showing measurements required).

(a) The height (h_1) of the camera lens above ground at the test site.

(b) The height (h_2) of the aircraft's wing tip above the ground at the run-up pad.

(c) The difference in elevation (h_3) between the run-up pad and the camera test site. This difference can be accurately determined by using a surveyor's level. (Note: It is desirable to place the camera as close to the aircraft as possible. If the camera is located close to the aircraft and on the run-up pad, the height difference (h_3) will be zero).

(d) The actual wing span (b) of the aircraft.

4.6.2 Flight Test Coordination and Pilot's Orientation

The flight observer is responsible for coordination of the flight test program. (If the flight observer is not completely qualified, the flight test engineers must coordinate the program). The observer should be familiar with the operational manual of the aircraft under test. He must brief the pilot and the ground site operator before the flight begins on all applicable parts of the following Section 4.6.3. Paragraph 5(b), which requires level unaccelerated flight while the aircraft is over the camera, is especially important for the pilot to understand. Examples of check lists for the flight test observer, pilot, and ground site operator are given in Sections 4.6.4, 4.6.5, and 4.6.6.

The flight observer also makes out a flight test plan for the pilot and the ground site operator, which states each test point required and the sequence of tests. Forms 4-4, 4-5, and 4-6 at the end of this section are examples of data cards which could be prepared by the flight observer.

4.6.3 Flight Test Procedure

(1) A minimum of three and a maximum of six fly-over passes should be made at each reference speed. Reference speeds for a complete camera fly-over calibration are listed below. All passes should be accomplished during a single flight and a minimum of time should elapse between when the aircraft takes off and lands.

(a) Normal landing configuration with gear and flaps extended. (Test at three different speeds which cover the safe operational limits of the aircraft).

(b) Normal approach configuration with gear and flaps extended. (Test at three different speeds which cover the safe operational limits of the aircraft).

(c) Normal approach configuration with gear retracted. (Test at three different speeds which cover the safe operational limits of the aircraft).

(d) Minimum safe speed with gear and flaps retracted.

(e) Maximum safe subsonic Mach number with gear and flaps retracted.

(f) Three or more different intermediate speeds between minimum and maximum safe speeds with gear and flaps retracted.

The above requirements are applicable for original calibration of the airspeed system following construction or major overhaul or modification to the airframe. Some of the flight conditions (a) through (d) might be redundant for some aircraft and could therefore be eliminated.

For a recalibration check of an aircraft previously calibrated (those having calibration cards or graphs for the static pressure system), it should only be necessary to conduct 1(c), (d) and (e) from above. The flight observer should review the aircraft's operational manual and test objectives to see if additional test points are necessary.

If the aircraft will subsequently be calibrated at altitude, using either the "Pacer" Method or "Radar Tracking" Method, a low airspeed for use as an altitude reference should be selected and included as a test condition under (f) above.

(2) The static port calibrator is turned on and allowed to come to temperature equilibrium. <u>The unit remains ON throughout the flight test program</u>.

(3) Immediately preceding the flight tests, the aircraft is taxied to the ground run-up pad and faced into the wind. The engines are shut down, or idled so as to eliminate air flow over the static pressure sensing ports. The following steps are completed in the order shown.

(a) Record calibrator's zero pressure signal and zero and full-scale calibration signals on oscillograph trace.

(b) Trap barometric pressure sample in calibrator. The following measurements are obtained immediately after the sample is trapped.

(c) Record zero pressure signal with trapped sample on oscillograph trace. (Note: The oscillograph will now also record altimeter trace and airspeed zero trace. If used, the total temperature trace and zero traces for angle of attack and angle of sideslip will also be recorded).

(d) Record flight observer's meter reading.

(e) Record barometer at ground test site. (Readings are taken after a gentle tapping on the face plate of the instrument).

(f) Record temperature at ground test site.

(g) Record time when pressure sample is trapped.

(4) The aircraft takes off and prepares for the camera fly-over passes. Minimum altitudes consistent with safe flying conditions should be maintained throughout the flight.

(5) The aircraft then flies directly over the camera, using the side edge of the runway for adjustment, at the reference speeds noted in Item (1). The following factors are important to the flight test portion of this program.

(a) The nominal height of the aircraft above the test site is <u>four wing spans</u> of the aircraft. (The height of the aircraft above the test site should not exceed 500 feet, nor be greater than six times the wing span of the aircraft. The height of the aircraft should not be less than two times the wing span of the aircraft).

(b) All test runs over the camera are made in <u>level unaccelerated flight</u>. The aircraft is stabilized on the approximate indicated airspeed and <u>approximate</u> desired altitude prior to reaching the camera site and maintains constant airspeed (constant power setting) and level altitude during the run. Stabilized flight is more important than the exact altitude or airspeed. The aircraft should not be banked during the runs. Flights into the wind or downwind are preferable.

(c) The tests should be conducted under non-turbulent atmospheric conditions (smooth air). Consideration should be given to conducting tests in the early part of the day to minimize air turbulence due to solar heating of the terrain.

(d) Due to close proximity of the flights to the ground, necessary approval may be required prior to the flight tests. The approach path of the aircraft should take into account its proximity to any residential area.

(e) With the noted exception of single place aircraft, all in-flight readings are made and recorded by a qualified observer. A qualified observer is defined as an experienced engineer, pilot, instrument mechanic, or person familiar with the special instruments being recorded, and the procedures described in this section.

(7) The observer in the test aircraft activates the oscillograph as the aircraft approaches the camera test site. Before each pass over the camera, he obtains a short trace of the calibrator's zero and full-scale calibration signals on the oscillograph. Upon receiving a signal from the ground that the aircraft is within the field of view of the camera, the observer makes a time mark on the oscillograph trace and records the film footage number (if necessary), and records the Observer's Meter reading. Simultaneously the ground site operator photographs the aircraft, after which he immediately records the ground barometer reading and temperature reading. Time of readings is recorded by both the aircraft observer and the ground operator.

The aircraft observer records parameters necessary to obtain the aircraft gross weight, during the pass.

If automatic recording of airspeed on the oscillograph is not used, the aircraft observer records the special airspeed indicator reading when he receives the ground signal signifying that the aircraft is being photographed.

(8) At completion of the test flight the aircraft lands, is taxied to the run-up pad, faced into the wind, and the engines shut down (or idled to prevent disturbance of pressure at the aircraft's static pressure ports). The calibrator remains on. The following steps are completed in the order shown.

(a) With pressure sample still trapped in calibrator, run a post-flight trace of all parameters on the oscillograph, including the zero and full-scale calibration signals from the calibrator. Record Observer's Meter reading.

(b) At the same time, record barometer, temperature and time at the ground test site.

(c) Release trapped pressure sample in oscillograph.

(d) Record zero pressure signal and zero and full-scale calibration signals on oscillograph trace. Record Observer's Meter reading.

(9) Data reduction and determination of the static pressure position error of the aircraft for each of the flight conditions is outlined in detail in Section 8.

4.6.4 Check List for Flight Test Observer

A. Special Airborne Equipment:
   1. Static Port Calibrator.
   2. Recording Oscillograph.

   Optional Airborne Equipment:
   1. Pilot's Meter.
   2. Special Airspeed Indicator.

B. Aircraft Installation:
   1. Install calibrator and oscillograph (and pilot's meter and airspeed indicator).
   2. Leak check pitot and static system.

C. Prior to Flight:
   1. Determine test points required (check aircraft operational manual).
   2. Determine method for obtaining gross weight of aircraft.
   3. Fill out data cards and flight test plan (Forms 4-4, 4-5, and 4-6).
   4. Coordinate with pilot and ground observer and have a thorough preflight briefing with both.
   5. If necessary, obtain air traffic or legal approval for tests over residential areas.
   6. Set watch with watches of pilot and camera operator.

D. Flight: (Record at each test point and when pressure sample is trapped).
   1. Oscillograph trace number; activate calibrate signals.
   2. Meter reading and scale factor.
   3. Gross weight information.
   4. Time.

E. Post Flight:
   1. Gather all data cards.
   2. Reduce data using Forms 8-2 in Section 8.

4.6.5 Check List For Ground Site Camera Operator

A. Ground Equipment:
   1. Camera.
   2. Voice communication equipment.
   3. Precision aneroid barometer.
   4. Thermometer.
   5. Instrument Shelter.
   6. Clock.

B. Special Measurements:
   1. Calibrate camera focal length.
   2. Measure height of camera lens above ground.
   3. Measure height of aircraft's wing tips above ground.
   4. Measure difference in elevation between run-up and camera test site.
   5. Measure wing span of aircraft.

C. Prior to Flight:
   1. Preflight briefing with pilot and flight test observer.
   2. Review ground site operator's data card (Form 4-6).
   3. Shoot test frame at start of film roll.

D. Flight Test: (Record at each test point and when pressure sample is trapped in calibrator).
   1. Barometer reading.
   2. Temperature at test site.
   3. Film frame number.
   4. Time.

E. Post Flight:
   1. Shoot test frame at end of the film roll.
   2. Develop film as continuous roll.

4.6.6 Check List for Pilot

1. Pre-flight briefing with flight observer and camera operator.
2. Review pilot's test sequence card (Form 4-4).
3. Minimum altitudes consistent with safe flying conditions should be maintained throughout the flight.
4. Use side edge of runway for reference, flying directly over the camera is important.
5. Nominal height of aircraft above test site is four wing spans.
6. Stabilize on airspeed and approximate desired altitude prior to reaching the camera site and maintain constant airspeed (constant power setting) and level altitude during the run.
7. All tests over the camera are made in level unaccelerated flight.
8. The aircraft should not be banked during the run.
9. Conduct tests under non-turbulent atmospheric conditions (smooth air).
10. Flights into the wind or downwind are preferable.

FORM 4-4

PILOT'S TEST SEQUENCE CARD

(Fill in before tests begin)

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Pilot:

Test Point	Aircraft Config.	Nominal Altitude (xxxx.) ft	Nominal Airspeed (xxx.) knots	Remarks
Initial	-----	-----	0	Taxi to camera site, face into wind, shut down or idle engine(s)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
FINAL	-----	-----	0	Taxi to camera site, face into wind, shut down or idle engine(s)

FORM 4-5

FLIGHT OBSERVER'S DATA CARD

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Data Taken By:

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)					
Test Point	Aircraft Config.	Nominal Altitude	Nominal Airspeed	Oscillograph Trace No.	Meter Read.	Meter Scale Factor	Gross Wt.	Time	Remarks
		(xxxx.)ft	(xxx.)knots		(xxx.)	X(x.)	(xxx,x00) lbs		
INITIAL	-----	-----	0						
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
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19									
20									
21									
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23									
24									
25									
26									
27									
28									
29									
30									
FINAL	-----	-----	0						

FORM 4-6

GROUND SITE OPERATOR'S DATA CARD

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Data Taken By:

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)				
Test Point	Aircraft Config.	Nominal Altitude (xxxx.) ft	Nominal Airspeed (xxx.) knots	Barometer Reading (xx.xxx) "Hg	Temp. At Test Site (xx.) °F	Film No	Time	Remarks
INITIAL	-----	-----	0			--		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
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28								
29								
30								
FINAL	-----	-----	0			--		

SECTION 5

PACER AIRCRAFT CALIBRATION METHOD

5.1 INTRODUCTION

The "Pacer Aircraft" method is a simple and commonly used method for flight calibration of aircraft at altitude. The test aircraft is calibrated using a previously calibrated aircraft called a pacer. The two aircraft fly side-by-side at the same altitude. The pacer with its known position error acts as a reference for determining true static pressure. Typical flight paths for the aircraft are given in Figure 5.1.

Static port calibrators are installed in both the pacer and test aircraft. Static pressure samples at altitude are sealed in each calibrator when both aircraft fly together at a low airspeed reference condition. The test aircraft should have a known position error at this reference condition, determined previously from "Camera Fly-Over" calibration tests. The difference between the pressure samples in each calibrator at the initial sealing condition is the difference between the known static pressure errors of the pacer and test aircraft.

Calibration data for the test aircraft is then obtained when the two aircraft fly together at other airspeeds. The calibrator in the test aircraft is used to maintain a zero pressure differential between the aircraft's measured pressure and the trapped pressure sample. Static pressure error of the test aircraft is obtained by measuring any pressure differential on the pacer's calibrator and correcting for the pacer's known position error and initial conditions when the pressure samples were sealed.

As an alternate method, the pilot's primary full range altimeter can be used in the test aircraft instead of the static port calibrator. The test aircraft first flies at a low airspeed reference condition at which the static pressure position error is known from previous calibration. At this condition a reference pressure sample is sealed in the pacer aircraft's

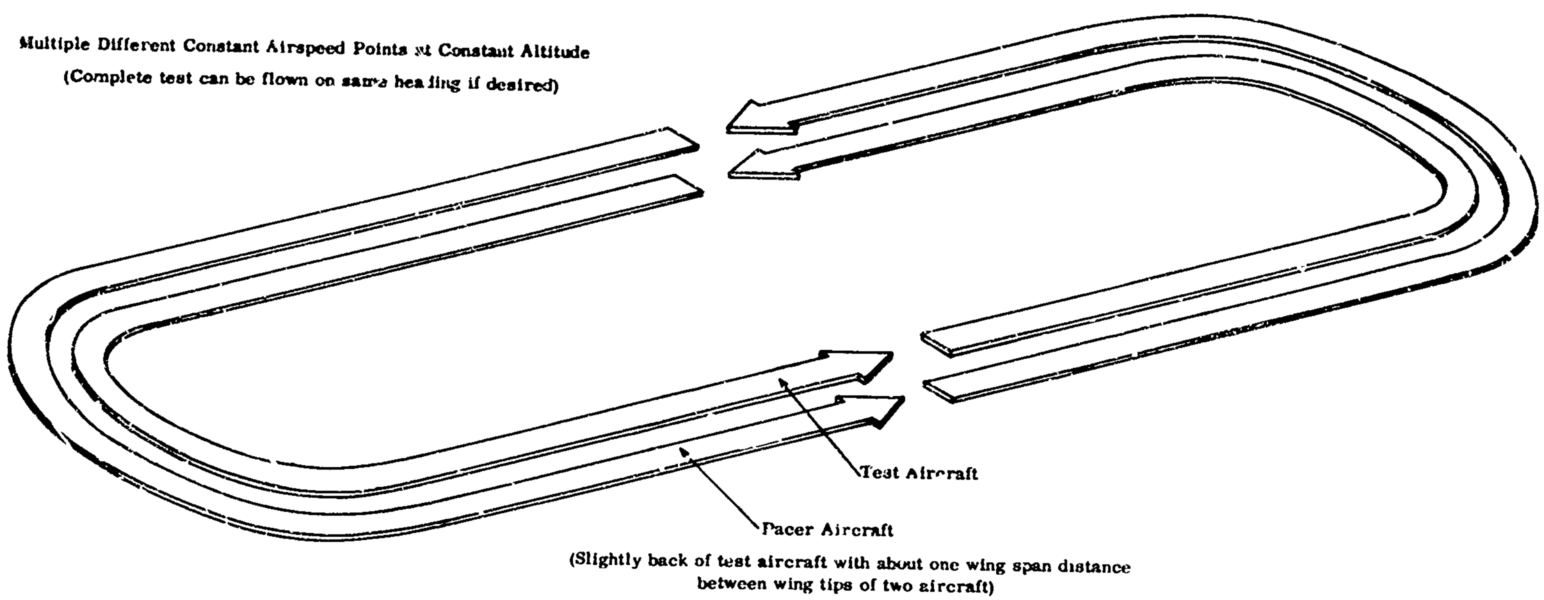

Figure 5.1

Typical Flight Paths for Pacer Aircraft Method of Flight Calibration

calibrator. The pilot in the test aircraft is then instructed to fly constant indicated altitude, and pressure differential as a function of airspeed is measured by the pacer aircraft. This method would be less accurate, but has the advantage that no modifications to the test aircraft are necessary. A comparison of expected accuracies, using full range altimeter vs using static port calibrator, is given in Section 3.4.2.

No special ground equipment is needed for the "Pacer Aircraft" calibration method. Testing is not restricted to a specific geographical location.

5.2 EQUIPMENT

5.2.1 Pacer Aircraft

Any type of aircraft with speed and altitude capabilities consistent with those needed for the specific flight test can be used as a pacer. The operational range for the pacer and test aircraft must be compatible. The pacer should have a small static pressure position error which is completely defined, over the speed and altitude test region, from previous altitude calibration using one or more of the Pacer, Radar Tracking, or Trailing Cone methods. A preferred location for the pacer's static ports is on a nose boom mounted flight test or aerodynamically compensated pitot-static tube. The position error will then be small, repeatable, and insensitive to angle of attack and angle of sideslip changes when the installation is of proper design. A calibrated trailing cone assembly, described in Section 7.2, could also provide a suitable static pressure source. Since the pacer aircraft is looked upon as a standard, it is required that extensive repeat calibration be performed periodically to insure the reliability of the pacer has been maintained.

The pilot for the pacer aircraft should be trained in close proximity flying and be proficient in the special techniques required for this calibration method.

5.2.2 Flight Equipment

Flight test equipment for the pacer is listed below. Only the static port calibrator and the pilot's meter, Item (1) and

Item (2), are required in the test aircraft. (Note: The pilot's primary altimeter can be used in the test aircraft, in lieu of the calibrator and pilot's meter, if high accuracy is not required for the tests). Some of the other equipment listed could be used on certain high performance test aircraft to obtain optimum accuracy. The equipment in each aircraft is monitored and data is recorded by a qualified flight observer, or the pilot in the case of a single place aircraft. A qualified observer is defined as an experienced engineer, pilot, instrument mechanic or person familiar with the special instruments being recorded and the procedures described in this section.

(1) Calibrator: A static port calibrator is installed at the observer's station in each aircraft. Description of a typical calibrator is given in Section 2 of Appendix A. The calibrators instruction manual should be reviewed thoroughly before the unit is used. The calibrators shall have been calibrated within the preceding 10 days.

(2) Pilot's Meter: The pilot's meter is installed on or near the flight instrument panel of the test aircraft and in the pilot's field of view. The meter indicates pressure differential of the static port calibrator and the pilot of the test aircraft flies the aircraft at the zero differential meter reading. Description of a typical pilot's meter is included in Section 2 of Appendix A.

Installation of a pilot's meter in the cockpit of the pacer is optional.

(3) Airspeed Indicator: A precision airspeed indicator with a certified scale error correction and repeatability accuracy of ± 2.5 knots is needed to determine airspeed of the pacer aircraft. Installation is at the flight observer's station. The indicator is to be selected for low hysteresis and good stability and repeatability and certified within the preceding 30 days. (The manometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg). A calibration chart of airspeed indicator instrument correction (ΔV_{ic}) vs indicated airspeed (V_i) is needed with the airspeed indicator for use in data reduction.

The pilot's primary airspeed indicator is used in the test aircraft. The airspeed indicator should have a calibration chart of ΔV_{ic} vs V_i, determined from a recent calibration. If the airspeed indicator is corrected for position error by an air data computer, this correction must be known and subtracted from the observed readings. Use of a special airspeed indicator at the observer's station in the test aircraft is optional.

(4) Altimeter: A calibrated altimeter is installed in the pacer aircraft at the flight observer's station. The altimeter is selected to have a good stability and repeatability, low hysteresis, and small temperature dependency. A precision altimeter (calibrated to ± 20 feet or 0.25% whichever is greater) should be used on all jet aircraft and is recommended for other aircraft. The altimeter shall be calibrated within the preceding 30 days and meet the requirements of the latest FAA Standard Order on altimeters. (The barometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg, References 14 and 41). A calibration chart of altimeter instrument correction (ΔH_{ic}) vs uncorrected altimeter reading (H_i) is needed with the altimeter for use in data reduction. The calibration of the special altimeter shall be at a setting of 29.92 inches Hg.

The pilot's primary altimeter is used in the test aircraft to establish the reference condition for sealing of pressure samples in the calibrators. The altimeter should have a calibration chart of ΔH_{ic} vs. H_i determined from a calibration within the preceding 24 calendar months by a competent repair station. If the altimeter is corrected for position error by an air data computer, this correction must be known and subtracted from the observed reading. Installation of a special altimeter at the observer's station in the test aircraft is optional and is used only as a redundant check on the pacer's altimeter.

(5) Recording Oscillograph: An airborne recording oscillograph, or a photo-panel, gives an automatic and continuous recording of flight parameters and could be used in the pacer aircraft. It would replace the special airspeed indicator (3)

and altimeter (4) at the observer's station in the pacer aircraft.

An oscillograph can also be used to record accurately pressure differential from the static port calibrator. To obtain the desired resolution, a 12" oscillograph is recommended. At least 10 inches of the 12-inch trace width should represent the differential pressure range of the calibrator. The recording of compressible dynamic pressure (q_{cm}), for airspeed, and absolute static pressure (p_m), for altitude, on the oscillograph trace can be obtained using multi-sweep transducers of the SFIM type (Reference 27) or equivalent. The q_{cm} and p_m transducers give a continuous trace of these parameters and could be used to detect variations in airspeed and altitude immediately before and after a calibration point as well as to obtain the exact value of q_{cm} and p_m at the calibration point.

A time recording is desirable on the galvanometer trace; although if not available, the flight observer can mark the film with a spare trace channel and record the film footage number when a calibration point is taken.

Angle of attack (α), and possibly angle of sideslip (β), traces on the oscillograph might also be desirable if position error is α or β dependent.

The recording oscillograph is laboratory calibrated at the same time as static port calibrator, to determine conversion constants and any nonlinearity of the trace signals.

If the oscillograph is not used in the pacer aircraft, the flight observer must manually record readings of the observer's indicator on the static port calibrator, airspeed indicator, altimeter, and possibly angle of attack meter. This might be undesirable if the test aircraft has a large position error or for high transonic and supersonic Mach number calibration when stability of speed and altitude between the aircraft could be a problem.

(6) Angle of Attack Meter: Position errors for static pressure port installations, especially flush fuselage installations, on some aircraft can vary appreciably with angle of attack of the

aircraft. Obtaining the relationship of position error of the test aircraft with changing angle of attack could be desirable. Incorporation of angle of attack in the presentation of flight test data is included in Section 8. The primary angle of attack sensor of the aircraft should be used. The pilot's angle of attack meter can be read or a meter installed at the observer's station in the aircraft. Output signals from some angle of attack sensors can also be recorded directly on a recording oscillograph.

(7) Voice Communication Equipment: Communication is needed between the two flight observers, the two pilots and the pilot and flight observer in each aircraft.

5.3 FLIGHT TEST PROGRAM

5.3.1 Pre-Flight Procedures

The following installations are made in both the pacer and test aircraft prior to the flight test. The oscillograph, or altimeter and airspeed indicator, are optional equipment on the test aircraft, as described above in Section 5.2. (If a static port calibrator is not installed in the test aircraft, only the pressure check in Item 4 applies).

(1) "T"-shaped pressure fittings are placed in the primary static pressure line of the test aircraft and in the primary static pressure and pitot pressure lines of the pacer aircraft. Special tubing is used between each "T" and the calibrator (and altimeter and airspeed indicator or oscillograph) mounting location in the aircraft. The tubing length should be as short as possible. Flexible, non-collapsible tubing is permissible if the installation is not permanent. The static tubing should have an internal diameter of about 0.305 inch and the pitot tubing should have an internal diameter of about 0.180 inch. The "T" fittings can be made permanent installations on the aircraft and are to be disconnected from the special tubing and capped when not used for calibration flights.

(2) The special altimeter and airspeed indicator, or recording oscillograph, are placed at the observer's station in the pacer aircraft. Altitude and airspeed pressure transducers

are connected to the special pitot and static pressure tubings. A "T" is placed in the static pressure line at the observer's station to allow connection to the calibrator unit.

(3) The static port calibrator is placed at the observer's station and connected to the static pressure line.

(4) After insertion of the calibrator and special altitude and airspeed pressure transducers, the aircraft primary pitot and static pressure lines are sealed and pressure checked with an airspeed system field check unit. With the source of vacuum isolated, the recommended maximum allowable leak rate for the complete static pressure system over a period of 5 minutes is twenty (20) feet/minute at an initial pressure altitude of 30,000 feet. If the range of the pilot's altimeter does not have a calibrated range of 30,000 feet, a pressure sufficient to produce 3/4 of full scale deflection on the altimeter shall be applied. With the source of pressure isolated, the maximum allowable leak rate for the complete pitot pressure system over a period of 5 minutes is 2 knots/minute at the maximum airspeed attainable with the aircraft.

5.3.2 Reference Calibration Point of Test Aircraft at Altitude

At the start of the flight test runs at a particular altitude, a reference pressure is sealed in the static port calibrator of each aircraft. It is important that the difference between reference pressures of the two calibrators be exactly known.

The basic method of obtaining correct pressure levels in both calibrators is to have a previous calibration of the test aircraft at a low airspeed, (V_m). This calibration is performed using the "Camera Fly-Over" method described in Section 4.6. To obtain the reference pressure sample, the test aircraft flies at this same airspeed (V_m) at the desired testing altitude (A_m). The pacer aircraft and test aircraft fly side-by-side in level unaccelerated flight, and the observers in each aircraft trap reference pressure samples simultaneously. The pacer must also have a well defined static pressure position error at this same reference airspeed. Any difference in the reference pressures sealed in the calibrators of the two aircraft is then the difference between the known position errors of the pacer and test

aircraft at the reference airspeed and altitude.

It is important that Mach number corresponding to the reference airspeed should not enter the compressibility region of influence for the test aircraft's static pressure system. Compressibility influences are present when static pressure position error, in the form $\Delta p/q_c$, changes appreciably with increasing Mach number for a constant aircraft angle of attack. Generally, the reference airspeed should always correspond to Mach numbers less than 0.6 at altitude. Figure 5.2 shows the reference airspeed corresponding to Mach number 0.6, as a function of altitude (H_m). Obtaining an acceptable reference airspeed, from "Camera Fly-Over" calibration of the test aircraft, in the clean configuration, might not be possible for use at test altitudes above about 40,000 to 50,000 feet. If flight calibration is desired at higher altitudes, a low (second) reference airspeed can be obtained when calibrating the test aircraft at an intermediate altitude, say 20,000 feet, using the present "Pacer" method. This second reference airspeed can then be used as the reference condition at higher altitude when obtaining pressure samples for the pacer and test aircraft. Again, the pacer must also have a well defined static pressure position error at this same reference airspeed and altitude.

5.3.2.1 Alternate Methods: Using Calibrators in Both Aircraft:

Reference pressure samples for the calibrators in the pacer and test aircraft can be obtained from several alternate methods. For specific applications, these methods could offer advantages to the basic "low airspeed reference" method described above.

One alternate would be to pre-set the reference pressure level in each calibrator while both aircraft are on the ground. The test aircraft then does not need a previously calibrated airspeed point. The pressure level can be set to any desired pressure altitude. However, it is important that identical pressures are sealed in each calibrator. The pacer and test aircraft are parked together on the ground. The calibrators in each aircraft are interconnected to a common vacuum source and charged at the same time. Both calibrators must be warmed

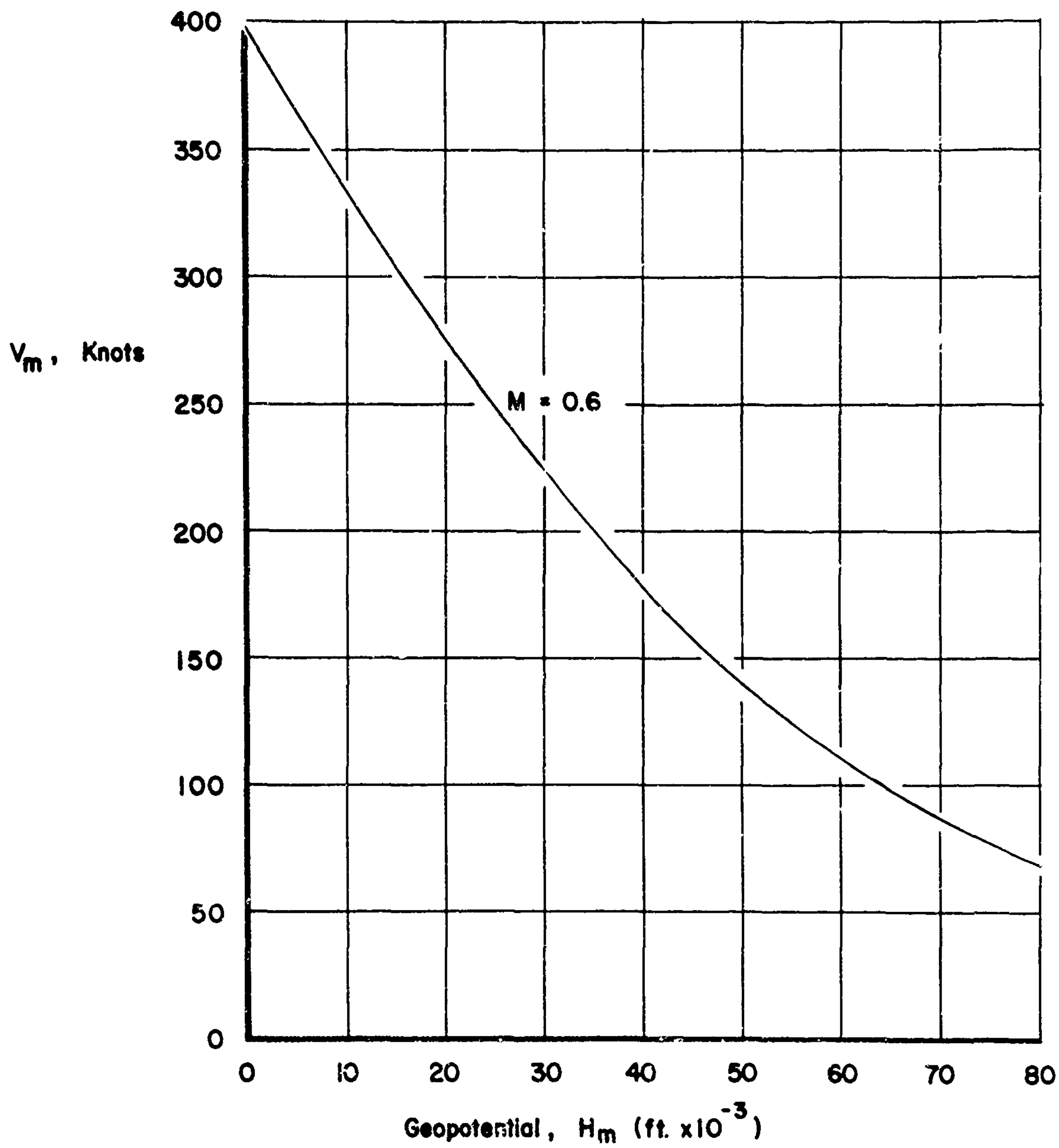

Figure 5.2

Airspeed as a Function of Altitude for a Mach Number of 0.6

up and at temperature equilibrium when the pressure sample is sealed in each unit.

To facilitate charging, two valves can be placed in the line connecting the calibrator to the aircraft's static pressure system. One valve will isolate the calibrator from the aircraft's static system and the other valve is used to allow placing a common pressure charging line from the vacuum source to the two calibrators. The charging system must be carefully pressure checked before use. Any leak could result in an unknown differential between the pressures sealed in each calibrator. Therefore, care should be exercised to select valves not susceptible to leakage. After the pressure sample is sealed in each calibrator, the valve from the calibrator to the charging system is closed and the charging line removed. The valve between the calibrator and the aircraft's static pressure system is opened and both aircraft are free to take off.

Ground charging of the calibrators in the pacer and test aircraft can be used for each test altitude. It can also be used for only the first test altitude, say 10,000 feet, and a low airspeed reference condition established at this altitude for use at the remaining test altitudes. For the other altitudes the procedure then reverts to the basic method described in Section 5.3.2.

Another alternate method to establish a reference pressure condition is available for test aircraft with nose boom or other static pressure source installation which is known to be insensitive to angle of attack. A high subsonic Mach number calibration point is established from "Camera Fly-Over" flight test calibration. Reference pressure samples for the calibrators in the pacer and test aircraft are then obtained while flying at this constant Mach number condition at the test altitude.

A supersonic reference point of known static pressure error can also be established for a test aircraft if it has a nose boom or other static pressure source installation which is known to be insensitive to angle of attack. The supersonic constant Mach number point can be obtained while calibrating at an intermediate altitude using the basic "low airspeed reference" method described in Section 5.3.2.

5.3.2.2 Alternate Method Using Full Range Altimeter in Test Aircraft

An alternate method [illegible] er calibration is to use the pilot's primary full range altimeter in the test aircraft instead of a static port calibrator. This method would be less accurate, but has the advantage that no modifications to the test aircraft are necessary. Testing procedures are the same as described in the following sections, 5.3.4 through 5.3.8, except that statements relating to the calibrator in the test aircraft can be omitted.

At the start of calibration runs at a particular altitude, the test aircraft first flies at a low airspeed reference condition. Position error for the test aircraft at this condition has been previously determined by flight calibration, performed using the "Camera Fly-Over" method described in Section 4. The pacer must also have a well defined static pressure position error at this same reference airspeed. At the reference airspeed and desired testing altitude, the pacer aircraft and test aircraft fly side by side in level unaccelerated flight. The observer in the pacer aircraft traps a reference pressure sample in his calibrator. The observer in the test aircraft, records the pilot's primary altimeter and airspeed indicator readings at the time of pressure sealing.

The pilot in the test aircraft maintains the same constant indicated altitude as he accelerates to and stabilizes on each airspeed test point. Any pressure differentials between the two aircraft, indicating a varying position error, is recorded by the calibrator in the pacer aircraft.

5.3.3 Flight Test Coordination and Pilots Orientation

The flight observer in the test aircraft is responsible for coordination of the flight test program. (If the flight observer is not completely qualified, the flight test engineer must coordinate the program). The observer should be familiar with the operational manual of the aircraft under test. He must brief the pilot and observer in the pacer aircraft and the pilot in the test aircraft before the flight begins on all applicable parts of the following Section 5.3.4. Particular attention

should be given to Steps (3) through (7) to assure that each person knows his responsibilities. This will alleviate confusion and excessive communication while the tests are being conducted. Examples of check lists for the pilots and flight observers are given in Sections 5.3.5, 5.3.6, 5.3.7, and 5.3.8.

The test aircraft's observer also makes out a flight test plan for each flight observer which states each test point required and the sequence of tests. Forms 5-1, -2, -3, and -4 at the end of this section are examples of data cards which could be prepared for the pilots and observers.

The number of data points required at altitude will depend on the type of test aircraft. The flight observer should review the operational manual for the test aircraft to determine the number of test points necessary for new certification or recalibration. The following applies to original calibration of the airspeed system following construction or major overhaul or modification to the airframe. At least five test points with gear and flaps retracted are needed at each altitude, including:

(a) Minimum safe speed.
(b) Maximum safe subsonic Mach number.
(c) Three or more different intermediate speeds between minimum and maximum safe speeds. (Additional points will be needed if flight extends supersonic).

A minimum of three data points should be taken at each test point. Tests should be conducted at three or more altitudes covering the operation range of the test aircraft to determine dependency of static pressure position error on changing angle of attack or aircraft gross weight.

At the lowest test altitude, 5,000 to 10,000 feet, the followi-- aircraft configurations should be included in the test program.

(a) Normal landing configuration with gear and flaps extended.

(b) Normal approach configuration with gear and flaps extended.

(c) Normal approach configuration with gear retracted.

For each configuration, test at three different speeds which cover the safe operational limits of the aircraft. A minimum of three data points should be taken at each airspeed test point.

For a recalibration check of an aircraft previously calibrated (those having calibration cards or graphs for the static pressure system) it should only be necessary to conduct an abbreviated test. The flight observer should check the operational manual and test objectives for requirements.

The tests should be conducted under non-turbulent atmospheric conditions (smooth air). Consideration should be given to conducting tests in the early part of the day and over large bodies of water or constant color terrain. It might be necessary for the test aircraft's pilot to search for smooth air during the testing period.

A rendezvous point for the two aircraft should be determined before the flight begins. (Preferred method is for aircraft to stay within visual contact throughout the flight).

5.3.4 Flight Test Procedure

The complete flight test procedure is described below for the case where the low airspeed method, Section 5.3.2, is used to obtain the correct reference pressure in each calibrator. It is assumed that static port calibrators are installed in both aircraft, the pacer aircraft is equipped with a special altimeter and a special airspeed indicator at the observer's station.

(1) Before take-off, the static port calibrators in both the pacer and test aircraft are turned on and allowed to come to temperature equilibrium. The calibrators remain on throughout the test flight.

(2) Both aircraft take off and fly to the pre-determined rendezvous point.

(3) At the first and lowest test altitude, the pilot in the test aircraft stabilizes on the previously calibrated reference airspeed. The pilot's altimeter and airspeed indicator, both corrected for scale error, are used to establish the reference condition. The altimeter is at a setting of 29.92 (inches Hg). After the reference condition has been established, the pilot in the test aircraft maintains constant power setting and heading and constant altimeter reading.

(4) The pilot in the pacer flies with the test aircraft and adjusts his altitude and airspeed so that the wing tips of the two aircraft are about one wing span of the larger aircraft apart, and the aircraft are flying side by side at the same altitude and velocity. The pacer aircraft is to the right of the test aircraft and only slightly back of the test aircraft, i.e., well forward of normal formation flying position. While data is being taken the difference in vertical height between the wing tips of the two aircraft must not exceed 5 feet. Flight proficiency of the pacer's pilot is very important to this operation.

(5) With both aircraft in level, unaccelerated flight, both flight observer's simultaneously seal reference pressure samples in the calibrators of each aircraft. Voice communication between the two pilots is used to coordinate the pressure sealing operation. The pilot of the test aircraft states when is is "STABLE" and the pacer's pilot calls the instant of pressure sealing by saying "RECORD" when he is in a stable condition. The following time coordinated steps are completed immediately after pressure sealing, while the aircraft are still flying together at the reference condition.

(a) Both observers record any initial pressure differential reading of indicator on calibrator.

(b) The pacer's observer records special altimeter and airspeed indicator readings. The test aircraft's observer records the pilot's altimeter and airspeed indicator readings, which are read and relayed to him by the pilot.

(c) The pacer's pilot observes any vertical height difference between the wing tips of the two aircraft at the time of pressure sealing and relates his estimate to the observer for recording. (If the estimated height difference

exceeds 5 feet, the pressure sealing operation must be repeated).

(d) Both observers record aircraft gross weight and/or angle of attack at the time of pressure sealing.

(e) Both observers record zero and full scale calibration readings of meter on calibrator. (The calibration signals can be recorded while the aircraft are adjusting their airspeed to the next calibration point).

(6) The pilot in the test aircraft then accelerates to and stabilizes on the next test airspeed. His altitude is maintained by holding zero on the pilot's meter. The pilot's airspeed indicator, corrected for scale error, is used to establish the correct airspeed condition. After the airspeed has been established, the pilot maintains constant power setting and constant heading.

The pilot in the pacer flies with the test aircraft and adjusts his altitude and airspeed so that the wing tips of the two aircraft are about one wing span apart and the aircraft are flying side by side at the same altitude and velocity. While data is being taken, the difference in vertical height between the wing tips of the two aircraft must not exceed 5 feet.

(7) Both aircraft maintain level, unaccelerated flight while the pilot of the test aircraft holds zero on the pilot's meter. The pilot in the test aircraft states when he is "STABLE" and the pacer's pilot calls the data point by saying "RECORD" when he is in a stable condition. When the "RECORD" signal is received:

(a) Both observers simultaneously record reading of indicator on calibrator.

(b) The pacer's observer records special altimeter and airspeed indicator readings. The test aircraft's observer records pilot's airspeed indicator reading.

(c) The pacer's observer records the pilot's estimate of any altitude difference between the two aircraft at the calibration point. (If the estimated height difference exceeds 5 feet, the data point must be repeated).

(d) Both observers record aircraft gross weight and/or angle of attack at the test condition.

(e) Both observers then record zero and full scale calibration readings of meter on calibrator.

(8) Steps (6) and (7) above are repeated for each airspeed calibration point at the test altitude. A recommended sequence is to calibrate at intervals from the lowest to highest airspeed taking two data recordings at each test point, and then to repeat the same test points while the airspeed is decreased.

(9) After the test points are obtained for a particular altitude, both aircraft stabilize at the initial reference airspeed condition, established in Step (5), and repeat Steps (6) and (7).

The pressure samples in each calibrator can then be released.

(10) Steps (3) through (9) are repeated for each test altitude. The test sequence should be from the lowest to the highest test altitude.

(11) Data reduction and determination of static pressure position error of the test aircraft is outlined in detail in Section 8.

5.3.5 Check List For Flight Observer in Test Aircraft

A. Special Airborne Equipment

1) Static Port Calibrator.
2) Pilot's Meter.
3) Voice Communication Equipment.

Optional Airborne Equipment

1) Special Airspeed Indicator.
2) Special Altimeter.
3) Angle of Attack Meter.

B. Aircraft Installation

1) Install calibrator and pilot's meter.
2) Leak check static pressure system.

C. Prior to Flight

1) Determine test points required (check aircraft operation manual).
2) Determine method for obtaining reference calibration point of test aircraft at altitude.
3) Determine method for obtaining gross weight of aircraft.
4) Fill out data cards and flight test plan (Forms 5-1, -2, -3, and -4).
5) Coordinate with both pilots and observer in pacer aircraft, and have a thorough preflight briefing with them.
6) Set watch with watches of pilots and other observer.

D. Flight (Record at each test point and when pressure sample is sealed)

1) Meter Reading.
2) Scale Factor.
3) Pilot's Altimeter reading (setting at 29.92).
4) Pilot's Airspeed Indicator reading.
5) Gross Weight information.
6) Time.

E. <u>Post Flight</u>

1) Gather all data cards.
2) Reduce data using Forms 8-3 in Section 8.

5.3.6 Check List for Flight Observer in Pacer Aircraft

A. Special Airborne Equipment

1) Static Port Calibrator.
2) Special Airspeed Indicator.
3) Special Altimeter.
4) Voice Communication Equipment.

Optional Airborne Equipment

1) Recording Oscillograph.
2) Pilot's Meter.
3) Angle of Attack Meter.

B. Aircraft Installation

1) Install calibrator, special airspeed indicator, and special altimeter.
2) Leak check pitot and static pressure systems.

C. Prior to Flight

1) Obtain static pressure position error charts or graphs for pacer aircraft.
2) Preflight briefing with pilots and observer in test aircraft.
3) Review data card for flight observer in test aircraft (Form 5-3).
4) Determine method for obtaining gross weight of pacer aircraft.

D. Flight (Record at each test point and when pressure sample is sealed).

1) Meter Reading.
2) Scale Factor.
3) Special Altimeter reading (setting at 29.92).
4) Special Airspeed Indicator reading.
5) Estimated height difference between aircraft.
6) Gross Weight information.
7) Time.

5.3.7 Check List for Pilot in Test Aircraft

1) Preflight briefing with both flight observers and pilot of pacer aircraft.
2) Review pilot's test sequence card (Form 5-1).
3) Determine rendezvous point at altitude for start of test.
4) All test data must be taken while flying through smooth air (Non-turbulent atmospheric conditions).
5) At each test condition maintain constant power setting and heading and constant pressure altitude (zero reading on pilot's indicator).
6) Tell pacer's pilot when you are "STABLE" at the test condition, then maintain constant pressure altitude until after pacer's pilot says "RECORD".
7) Read altimeter and airspeed indicator at "RECORD" signal and relay readings to your flight observer. (Altimeter set at 29.92 in. Hg).

5.3.8 Check List for Pilot in Pacer Aircraft

1) Pre-flight briefing with both flight observers and pilot of test aircraft.
2) Review pilot's test sequence card (Form 5-2).
3) Make sure pacer aircraft has speed and altitude capabilities consistent with those needed for the specific flight test.
4) Determine rendezvous point at altitude for start of test.
5) Fly with test aircraft and adjust altitude and airspeed so that wing tips of the two aircraft are about one wing span (of the larger aircraft) apart, and the aircraft are flying side by side at the same altitude and velocity.
6) The pacer aircraft is to the right and only slightly back of the test aircraft, i.e., well forward of normal formation flying position.
7) Maintain a visual "reference point" fix on test aircraft.
8) When test aircraft is "STABLE", maintain level, unaccelerated flight condition and call out "RECORD" when you are stable.
9) Estimate vertical height difference between the wing tips of the two aircraft when you say "RECORD". If the estimated height difference exceeds 5 feet, the test point must be repeated.
10) Flight proficiency in Steps 5 through 9 above must be well established before test data is taken.

FORM 5-1

TEST SEQUENCE CARD FOR PILOT OF TEST AIRCRAFT

(Fill In Before Tests Begin)

Date:
Aircraft Type:
Aircraft Number:
Test Location:
Pilot:

Test Point	Aircraft Config.	Test Altitude (xx,xxx.) Feet	Test Airspeed (xxx.) Knots	Remarks
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

FORM 5-2

TEST SEQUENCE CARD FOR PILOT OF PACER AIRCRAFT

(Fill In Before Tests Begin)

Date:
Aircraft Type:
Aircraft Number:
Test Location:
Pilot:

Test Point	Aircraft Config.	Nominal Altitude (xx,xxx.)Ft	Nominal Airspeed (xxx.)Knts	Remarks
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

FORM 5-3

DATA CARD FOR FLIGHT OBSERVER OF TEST AIRCRAFT

Date:
Aircraft Type:
Aircraft Number:
Test Location:
Data Taken By:

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)						
Test Point	Test Aircraft Config.	Nominal Test Altitude	Nominal Test Airspeed	Meter Reading	Scale Factor	Pilot's Altimeter Reading	Pilot's Airspeed Reading	Gross Weight	Time	Remarks
		(xx,xxx.) Feet	(xxx.) Knots	(xxx.)	X(x.)	(xx,xxx.) Feet	(xxx.) Knots	(xxx,x00) Lbs.		
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										

DATA CARD FOR FLIGHT OBSERVER [illegible]

(FILL IN BEFORE TESTS BEGIN)			(RECORD AT EACH TEST POINT)								
Test Point	Nominal Altitude (xx,xxx.) Feet	Nominal Airspeed (xxx.) Knots	Meter Reading (xxx.)	Scale Factor X(x.)	Altimeter Reading (xx,xxx.) Feet	Airspeed Reading (xxx.) Knots	Estimated Height Difference (xx.) Feet	Gross Weight (xxx,x00) lbs	Time	Remarks
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
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16										
17										
18										
19										
20										

SECTION 6

RADAR TRACKING CALIBRATION METHOD

6.1 INTRODUCTION

Accurate radar tracking of an aircraft is a method used for flight calibration of the aircraft's static pressure position errors at altitude. The calibration principles are similar to those used in the low altitude "Camera Fly-Over" method, Section 4, except that aircraft height is measured by radar tracking instead of by photographing the aircraft from the ground. A typical flight pattern for the aircraft is given in Figure 6.1. The test aircraft has a known position error at a low airspeed reference condition determined previously from "Camera Fly-Over" calibration tests. A static port calibrator installed in the test aircraft is used by the pilot to maintain constant measured pressure altitude (H_m). The measured pressure (P_m) corresponding to H_m is sealed in the calibrator while the aircraft is flying at the low reference airspeed. If, while flying at constant H_m at other test airspeeds, the aircraft's position error (H_m - H) changes with changing airspeed, the true pressure altitude (H) and therefore height (h) of the aircraft above the ground will change. These changes in height of the aircraft are measured by radar tracking.

The difference between (H) and (h) at the low speed reference condition is established by knowing the position error (H_m - H) of the test aircraft. Outside air static temperature, computed from measured total temperature, at the reference condition and at each test condition is used to relate measured height of aircraft (h) with true static pressure (p) at each test condition.

6.2 GROUND-BASED RADAR TRACKING

An accurate radar tracking set is required to measure elevation angle and slant range, from which height of the test aircraft above the ground can be computed. The monopulse AN/FPS-16 Instrumentation Radar (Reference 30) is recommended.

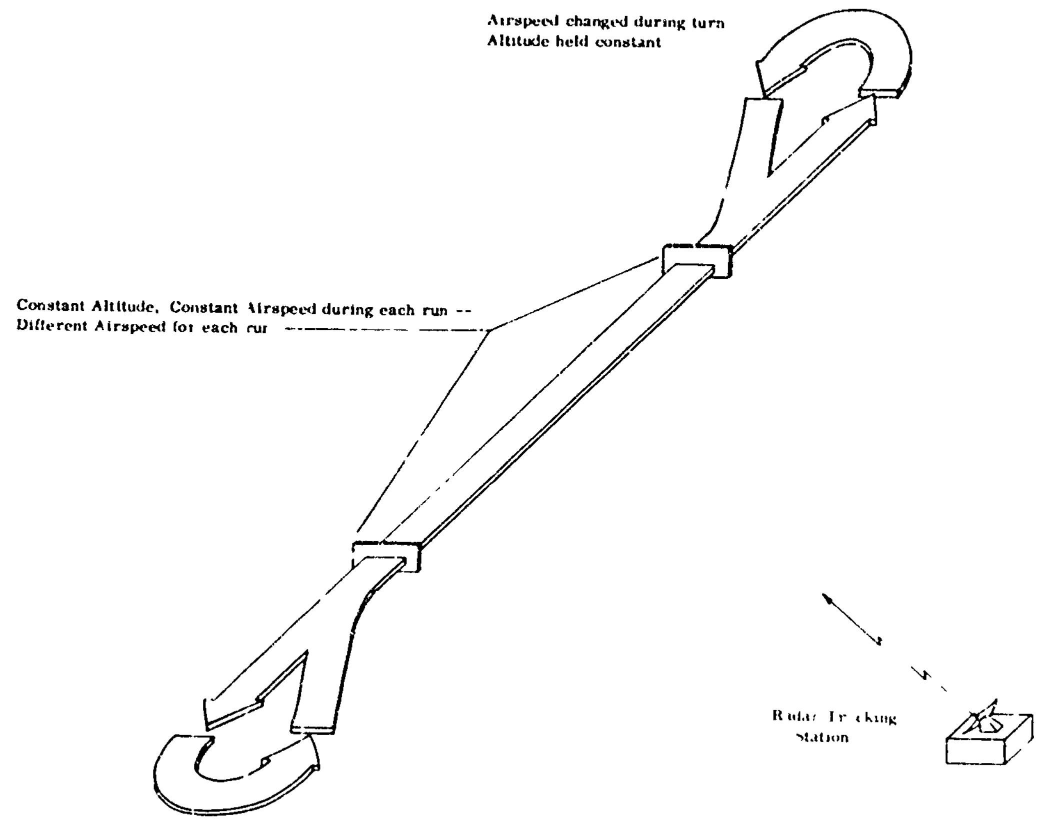

Figure 6.1

Typical Flight Pattern for Radar Tracking Flight Calibration Method.

It is a standard instrumentation radar for all three military services. There are a number of fixed AN/FPS-16 installations in the United States and throughout the world, including sets at the Atlantic Missile Range, Pacific Missile Range, White Sands Missile Range, United Kingdom, and Elgin Gulf Test Range. (References 31 and 32).

The AN/FPS-16 has a slant range accuracy of about ± 15 feet and elevation and azimuth angle accuracy of about ± 0.1 mils (1 mil = 1/6400 of a circle = 0.05625 degrees). The slant range and elevation angle measured by the AN/FPS-16 radar are recorded in increments of 1 foot and 0.0001°, respectively; the height of the test aircraft above the ground is computed from these values to increments of 1 foot. "Real" time recordings of aircraft height are available at most AN/FPS-16 installations.

The radar can also be used to vector the airplane into the test area. For each of the test runs, the airborne-instruments recordings and the radar recordings are synchronized by means of a radio voice signal from the radar control center.

6.3 AIRBORNE TEST INSTRUMENTATION

Flight test equipment for the aircraft is listed below. The equipment is monitored and data is recorded by a qualified flight observer, or the pilot in the case of a single place aircraft. A qualified observer is defined as an experienced engineer, pilot, instrument mechanic, or person familiar with the special instruments being recorded and the procedures described in this section.

(1) Calibrator: A static port calibrator is installed at the observer's station in the aircraft. Description of a typical calibration is given in Section 2 of Appendix A. The calibrator's instruction manual should be reviewed thoroughly before the unit is used. The unit shall be calibrated within the preceding 10 days.

(2) Pilot's Meter: The pilot's meter is installed on or near the flight instrument panel and in the pilot's field of view. The meter indicates pressure differential of the static

port calibrator and the pilot flies at the zero differential meter reading. A description of a typical pilot's meter is included in Section 2 of Appendix A.

(3) Airspeed Indicat . A precision airspeed indicator with a certified scale err r correction and repeatability accuracy of ± 2.5 knots is installed at the flight observer's station. The indicator is to be selected for low hysteresis and good stability and repeatability, and certified within the preceding 30 days. (The manometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg). A calibration chart of airspeed indicator instrument correction (ΔV_{ic}) vs indicated airspeed (V_i) is needed with the airspeed indicator for use in data reduction.

If the pilot's primary airspeed indicator is not compensated for position error by an air data computer, and meets the above requirements, it can be used in lieu of a special indicator installed at the flight observer's station.

(4) Altimeter: A calibrated precision altimeter is installed at the flight observer's station. It is used to establish the reference condition for sealing of a pressure sample in the static port calibrator. The altimeter is selected to have good stability and repeatability, low hysteresis, and small temperature dependency. The unit is to be calibrated within the preceding 30 days and meet the requirements of the latest FAA Technical Standard on altimeters and be calibrated to within an accuracy of ± 20 feet or 25%, whichever is greater. (The barometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg, References 14 and 41). A calibration chart of altimeter instrument correction (ΔH_{ic}) vs. uncorrected altimeter reading (H_i) is needed with the altimeter for use in data reduction. The calibration of the special altimeter shall be at a setting of 29.92 (inches Hg).

If the pilot's primary altimeter is not compensated for position error by an air data computer, and meets the above

requirements, it can be used in lieu of the special altimeter installed at the flight observer's station. Because an altimeter setting of 29.92 inches Hg is required, the pilot's altimeter should not be used if flight test altitudes are below 18,000 feet.

(5) Recording Oscillograph: An airborne recording oscillograph, or a photopanel, gives an automatic and continuous recording of flight parameters and could be used in the test aircraft. It would replace the special airspeed indicator, Item (3), and the special altimeter, Item (4), at the observer's station.

An oscillograph can also be used to record pressure differential accurately from the static port calibrator. To obtain the desired resolution, a 12" oscillograph is recommended. At least 10 inches of the 12-inch trace width should represent the differential pressure range of the calibrator. The recording of compressible dynamic pressure (q_{cm}), for airspeed, and absolute static pressure (p_m), for altitude, on the oscillograph trace can be obtained using multi-sweep pressure transducers of the SFIM type (Reference 27) or equivalent. The q_{cm} and p_m transducers give a continuous trace of these parameters and can be used to detect variations* in airspeed and altitude immediately before and after a calibration point, as well as to obtain the exact value of q_{cm} and p_m at the calibration point.

A time recording is desirable on the galvanometer trace; although if not available, the flight observer can mark the film with a spare trace channel and record the film footage number when a calibration point is taken.

A total temperature trace on the oscillograph could replace a manually read temperature indicator, Item (6) below, at the observer's station. Angle of attack (α), and possibly angle of sideslip (β), traces on the oscillograph might also be desirable in lieu of visually recorded meters, Item (7).

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*Variation in q_{cm} and p_m at the test condition could introduce pressure lag errors in the measured pressures and cause rejection of the data at the test point.

The recording oscillograph should be laboratory calibrated at the same time as the static port calibrator to determine conversion constants and any nonlinearity of the trace signals.

(6) Total Temperature Measurement: A total temperature measurement is needed on the test aircraft. Outside air static temperature, computed from total temperature and Mach number, is used to relate changes in height of aircraft (h), measured by the ground-based radar, to changes in true static pressure (p).

The pilot's total temperature indicator can be used or a separate temperature indicator or recorder can be installed at the observer's station in the aircraft. The recording oscillograph, Item (5), can also be used to record total temperature. Overall accuracy of the total temperature sensor system should be within ± 1°R and readability of the system should be within ± 0.2°R. Description and error analysis of a flight test total temperature system is included in References 16 and 33.

The total temperature sensor should have a fast time constant and high recovery factor. The USAF Type MA-1 Sensor per MIL-P-25726B or the total temperature sensor per MIL-P-27723A (USAF) is recommended. A discussion of these two sensors and others is given in References 34 and 35.

(7) Angle of Attack Meter: Position errors for static pressure port installations, especially flush fuselage installations, on some aircraft can vary appreciably with angle of attack of the aircraft. Obtaining the relationship of position error with changing angle of attack could be desirable. Incorporation of angle of attack in the presentation of flight test data is included in Section 8. The primary angle of attack sensor of the aircraft should be used. The pilot's angle of attack meter can be read or a meter installed at the observer's station in the aircraft. Output signals from some angle of attack sensors can also be recorded directly on a recording oscillograph, Item (5).

(8) Voice Communication Equipment: Radio voice communication is needed between the aircraft's pilot and flight observer and the ground radar control center.

(9) Radar Transponder: A special radar transponder, not an ATC Radar Transponder, in the aircraft with the antenna located on the underside of the fuselage is used to increase precision of the tracking radar. It provides a definite measurement point on the aircraft and essentially eliminates target glint or error due to scintillation. Photographs of a special flight test transponder installation are included in Reference 25.

6.4 FLIGHT-TEST PROGRAM

6.4.1 Prior to Flight Procedures

The following installations are made in the aircraft prior to flight test.

(1) "T"-shaped pressure fittings are placed in the primary static pressure and pitot pressure lines of the aircraft. Special tubings are used between each "T" and the calibrator (and altimeter and airspeed indicator or oscillograph) mounting location in the aircraft. The tubing length should be as short as possible. Flexible, non-collapsible tubing is permissible if the installation is not permanent. The static pressure tubing should have an internal diameter of about 0.305 inch and the pitot pressure tubing should have an internal diameter of about 0.180 inch. The "T" fittings can be made permanent installations on the aircraft and are to be disconnected from the special tubing and capped when not used for calibration flights.

(2) The special altimeter and airspeed indicator, or recording oscillograph, are placed at the observer's station in the aircraft. Altitude and airspeed pressure transducers are connected to the special pitot and static pressure tubings. A second "T" is placed in the special static pressure line to allow connection to the calibrator unit.

(3) The static port calibrator is placed at the observer's station and connected to the static pressure line.

(4) After insertion of the calibrator and special altitude and airspeed pressure transducers, the aircraft primary pitot

and static pressure lines are sealed and pressure checked with an airspeed system field check unit. With the source of vacuum isolated, the recommended maximum allowable leak rate for the complete static pressure system over a period of 5 minutes is twenty (20) ft/min at an initial pressure altitude of 30,000 feet. If the range of the pilot's altimeter does not have a calibrated range of 30,000 feet, a pressure sufficient to produce 3/4 of full scale deflection on the altimeter shall be applied. With the source of pressure isolated, the maximum allowable leak rate for the complete pitot pressure system over a period of 5 minutes is 2 knots/minute at the maximum airspeed attainable with the aircraft.

6.4.2 Reference Calibration Point of Test Aircraft at Altitude

At the start of the flight test runs at a particular altitude, a reference pressure is sealed in the static port calibrator of the test aircraft. It is important that the reference pressure be precisely known.

The basic method of obtaining a correct reference pressure level in the calibrator is to have a previous calibration of the test aircraft at a low airspeed (V_m). This calibration is performed using the "Camera Fly-Over" method described in Section 4. The test aircraft flies at this same airspeed (V_m) at the desired test altitude (H_m) and the flight observer traps the reference pressure sample when the aircraft is in level unaccelerated flight. The height (h) of the aircraft is simultaneously recorded by the radar control center.

It is important that Mach number corresponding to the reference airspeed should not enter the compressibility region of influence for the aircraft's static pressure system. Compressibility influences are present when static pressure position error, in the form $\Delta p/q_c$, changes appreciably with increasing Mach number for a constant aircraft angle of attack. Generally, the reference airspeed should always correspond to Mach numbers less than 0.6 at altitude. Figure 5.2 (page 5.10) shows the reference airspeed corresponding to Mach number 0.6 as a function of altitude (H_m). Obtaining an acceptable reference airspeed, from "Camera Fly-Over" calibration of the aircraft in the clean configuration, might not be possible for use at test altitudes;

a low (second) reference airspeed can be obtained when calibrating the test aircraft at an intermediate altitude, say 20,000 feet, using the present "Radar Tracking" method or the "Pacer" method, described in Section 5. This second reference airspeed can then be used as the reference condition at higher altitude when obtaining a pressure sample for the test aircraft.

6.4.3 Flight Test Coordination and Pilot's Orientation

The flight observer in the test aircraft is responsible for coordination of the flight test program. (If the flight observer is not completely qualified, the flight test engineer must coordinate the program). The observer should be familiar with the operational manual of the aircraft under test. He must brief the pilot and operator at the radar control center before the flight begins on all applicable parts of the following Section 6.4.4. Particular attention should be given to Steps (2) through (6) to assure that each person knows his responsibilities. This will alleviate confusion and excessive communication while tests are being conducted. Examples of check lists for the pilot and flight observer are given in Sections 6.4.5 and 6.4.6.

The test aircraft's observer also makes out a flight test plan for the pilot and operator at the radar control center which states each test point required and the sequence of tests. Forms 6-1, 6-2, and 6-3 are examples of data cards which could be prepared by the flight observer.

The number of data points required at altitude will depend on the type of test aircraft. The flight observer should review the operational manual for the test aircraft to determine the number of test points necessary for new certification or recalibration. The following applies to original calibration of the airspeed system following construction or major overhaul or modification to the airframe. At least five test points with gear and flaps retracted are needed at each altitude, including:

(a) Minimum safe speed.
(b) Maximum safe subsonic Mach number.
(c) Three or more different intermediate speeds

between minimun and maximum safe speeds. (Additional points will be needed if flight extends supersonic).

A minimum of three data points should be taken at each test point. Tests should be conducted at three or more altitudes covering the operation range of the test aircraft to determine dependency of static pressure position error on changing angle of attack or aircraft gross weight.

At the lowest test altitude, 5,000 to 10,000 feet, the following aircraft configurations should be included in the test program.

(a) Normal landing configuration with gear and flaps extended.

(b) Normal approach configuration with gear and flaps extended.

(c) Normal approach configuration with gear retracted.

For each configuration, test at three different speeds which cover the safe operational limits of the aircraft. A minimum of three data points should be taken at each airspeed test point.

For a recalibration check of an aircraft previously calibrated (those having calibration cards or graphs for the static pressure system) it should only be necessary to conduct an abbreviated test. The flight observer should check the aircraft operational manual and test objectives for requirements.

The tests should be conducted under non-turbulent atmospheric conditions (smooth air). Consideration should be given to conducting tests in the early part of the day, from about 3:00 A.M. to 8:00 A.M. and over large bodies of water or constant color terrain. Daylight is not needed for radar tracking and the early pre-dawn hours will probably give the smoothest atmospheric conditions.

The radar test site should pick the preferred area in space in which to conduct the tests. The aircraft should not fly directly over the radar, but rather off to one side at an elevation angle which will produce the best accuracy from the radar.

6.4.4 Flight Test Procedures

The complete flight test procedure for the "Radar Tracking" calibration method is described below. It is assumed that a special altimeter and special airspeed indicator are installed at the flight observer's station and that the visual meter on the calibrator is used to obtain differential pressure of the static port calibrator. It is also assumed that total temperature is obtained from an indicator and manually recorded.

(1) Before take-off, the static port calibrator is turned on and allowed to come to temperature equilibrium. The calibrator remains on throughout the flight test.

(2) The pilot takes off and flies to the radar test range. Radio voice communication is established with the radar control center and the radar is used to vector the airplane into the test area. The airplane is tracked, with the airborne transponder in operation, throughout the test program. When possible, the pilot should contact the radar control center just prior to take-off and establish a "pick-up" point in space. Arrangements for visual sighting by someone at the radar control center might be useful in finding the aircraft.

(3) At the first (and lowest) test altitude, the pilot stabilizes on the previously calibrated reference airspeed, Section 6.4.2. The observer's altimeter and airspeed indicator govern the establishment of the reference condition. The flight observer, if necessary, shall direct the pilot to the approximate correct airspeed and altitude. The pilot then uses his altimeter and airspeed indicator readings to maintain apparent test conditions. After the reference condition has been established, the pilot maintains constant power setting and constant altimeter reading.

(4) With the aircraft in level, unaccelerated flight over the radar test area, the flight observer seals a reference pressure sample in the calibrator. Simultaneously, through radio voice communication with the observer, the radar control center records slant range and elevation angle, (and therefore height) of the aircraft. Azimuth angle is also recorded. The following measurements are made by the flight

observer immediately after pressure sealing, while the aircraft is still at the reference condition.

(a) Record any initial pressure differential reading of indicator on calibrator.

(b) Record special altimeter and airspeed indicator readings.

(c) Record total temperature.

(d) Record angle of attack and/or aircraft gross weight.

(e) Record zero and full scale calibration readings from meter on calibrator. (The calibration signals can be recorded while the airplane is adjusting its airspeed to the next calibration point).

(5) Calibration points at the test airspeeds are now obtained at approximately the same location in space that the reference pressure sample was sealed in the calibrator. The radar control center vectors the aircraft back to the test location. While returning to the test location the pilot accelerates and stabilizes on the next test airspeed. His indicated pressure altitude is maintained by holding zero reading on the "pilot" meter, from the calibrator. The pilot's airspeed indicator is used to establish the correct airspeed condition. After the airspeed is established, the pilot maintains constant power setting and zero reading on the "pilot's" meter.

(6) The radar control center determines when the aircraft is again at the test location in space; established by using approximately the same slant range, elevation angle, and azimuth angle at which the reference pressure sample was sealed in the aircraft's calibrator. On voice command from the radar control center, the flight observer immediately records:

(a) Reading of pressure differential indicator on calibrator.

(b) Special airspeed indicator readings.

(c) Total temperature.

(d) Angle of attack and/or aircraft gross weight.

The pilot maintains level, unaccelerated flight during the above steps (a) through (d). The aircraft's slant range, elevation angle and azimuth angle are recorded by the radar control center

simultaneously with Step (a) above.

The flight observer then records zero and full scale calibration readings of meter on calibrator.

(7) Steps (5) and (6) are repeated for each airspeed calibration point at the test altitude. A recommended sequence is to calibrate at intervals from the lowest to highest a[illegible] speed. The sequence should be repeated three or four tim[illegible]. Total elapsed time should be kept to a minimum.

(8) After the test points are obtained for a particular altitude, the aircraft again stabilizes at the initial reference airspeed condit[illegible] established in Steps (3) and (4). Steps (5) and (6) are then repeated.

The pressure sample in the calibrator can then be released.

(9) Steps (3) through (8) are repeated for each test altitude. The test sequence should be from the lowest to the highest test altitude.

(10) Data reduction and determination of static pressure position error of the test aircraft is outlined in detail in Section 8.

6.4.5 Check List for Flight Observer in Test Aircraft

A. Special Airborne Equipment
   1) Static Port Calibrator
   2) Pilot's Meter
   3) Special Airspeed Indicator
   4) Special Altimeter
   5) Total Temperature Indicator
   6) Voice Communication Equipment
   7) Radar Transponder

   Optional Airborne Equipment
   1) Recording Oscillograph
   2) Angle of Attack Meter

B. Aircraft's Installations
   1) Install Special Airborne Equipment (Items 1 through 7 above.
   2) Leak check pitot and static pressure systems.

C. Prior to Flight
   1) Determine test points required (check aircraft operation manual).
   2) Obtain position error data for test aircraft at low airspeed point, (used to obtain reference calibration point at altitude).
   3) Establish test date and time with radar control center.
   4) Determine method for obtaining gross weight of aircraft.
   5) Fill out data cards and flight test plan (Forms 6-1, 6-2, and 6-3).
   6) Coordinate flight with test pilot and operator at the radar control center and have a thorough preflight briefing with both.

D. Flight (Record at each test point and when pressure sample is sealed).
   1) Meter Reading
   2) Scale Factor
   3) Special Altimeter Reading (Setting at 29.92)
   4) Special Airspeed Indicator Reading
   5) Gross Weight Information

6) Total Temperature
7) Time

E. Post Flight
1) Obtain test sequence card of pilot and data from operator at radar control center.
2) Reduce data using Forms 8-4 in Section 8.

6.4.6 Check List for Test Pilot

1) Pre-flight briefing with flight observer.
2) Review pilot's test sequence card (Form 6-1).
3) If possible contact radar control center just prior to take-off and establish a "pick-up" point in space.
4) Establish voice communication with radar control center and have the radar vector airplane into test area.
5) Conduct tests off to one side of radar site. Do not fly directly over radar site.
6) All test data must be taken while flying through smooth air (non-turbulent atmospheric conditions).
7) All test points are obtained at the same location in space.
8) At each test point maintain constant power setting and constant pressure altitude (zero reading on "pilot's" indicator).
9) Maintain level unaccelerated flight until all data, at each point, has been recorded by flight observer.

FORM 6-1

TEST SEQUENCE CARD FOR PILOT OF TEST AIRCRAFT

(Fill In Before Tests Begin)

Date:
Aircraft Type:
Aircraft Number:
Radar Test Site:
Pilot:

Test Point	Aircraft Config.	Test Altitude (xx,xxx.) Feet	Test Airspeed (xxx.) Knots	Remarks
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

FORM 6-2

DATA CARD FOR OPERATOR OF RADAR CONTROL CENTER

Date:
Aircraft Type:
Aircraft Number:
Radar Test Site:
Data Taken By:

(FILL IN BEFORE TESTS BEGIN)			(RECORD AT EACH TEST POINT)				
Test Point	Nominal Test Altitude	Nominal Test Airspeed	Slant Range (xxx,xxx) Feet	Elevation Angle (xx.xxxx) Degrees	Azimuth Angle (xx.xxxx) Degrees	Aircraft Height* (xx,xxx) Feet	Remarks
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

*Computed From Slant Range and Elevation Angle. (May be filled in after tests).

FORM 6-3

DATA CARD FOR FLIGHT OBSERVER

Date:
Aircraft Type:
Aircraft Number:
Radar Test Site:
Data Taken By:

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)						
Test Point	Test Aircraft Config.	Nominal Test Altitude (xx,xxx.) Feet	Nominal Test Airspeed (xxx.) Knots	Meter Reading (xxx)	Scale Factor X(x.)	Altimeter Reading (xx,xxx.) Feet	Airspeed Reading (xxx.) Knots	Gross Weight (xxx,x00.) lbs	Total Temp. (xxx.x) °R	Time
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
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25										

SECTION 7

TRAILING CONE CALIBRATION METHOD

7.1 INTRODUCTION

True static pressure at an aircraft's flight altitude can be obtained from static holes placed in a hollow tube extending behind the aircraft. The tube is kept straight and at approximately zero degrees angle of attack by a non-lifting drag cone attached to the end of the tube. The hollow tube plus drag cone is called a "Trailing Cone" assembly. It can be used for flight calibration of an aircraft's static pressure position errors over the entire Mach number-altitude flight envelope of the aircraft.

A brief description of a trailing cone assembly is given in References 36, 39, and 40. True static pressure is sensed by a set of holes placed around the circumference of the hollow tube, at a distance ahead of the drag cone sufficient to eliminate pressure influence from the cone. Distance of the static holes behind the aircraft needed to obtain true static pressure is dependent on the size and type of aircraft. Extension length is about 100 feet for larger turbojet aircraft and less for smaller aircraft. The distance should be determined for each aircraft configuration by flight test evaluation.

The hollow tube transmits the true static pressure (p) to an accurate, small range, differential pressure gage which measures directly the static pressure position error (p_m - p); p_m is "measured" static pressure from the aircraft's primary static pressure source, e.g. flush static ports or pitot-static tube. Because the aircraft carries its own reference, pressure (p) from trailing cone assembly, flight calibration is conducted without the aid of other aircraft or special ground equipment and is not dependent on testing over specific geographical locations. A typical flight pattern for trailing cone flight calibration is shown on Figure 7.1; however, any suitable route may be used.

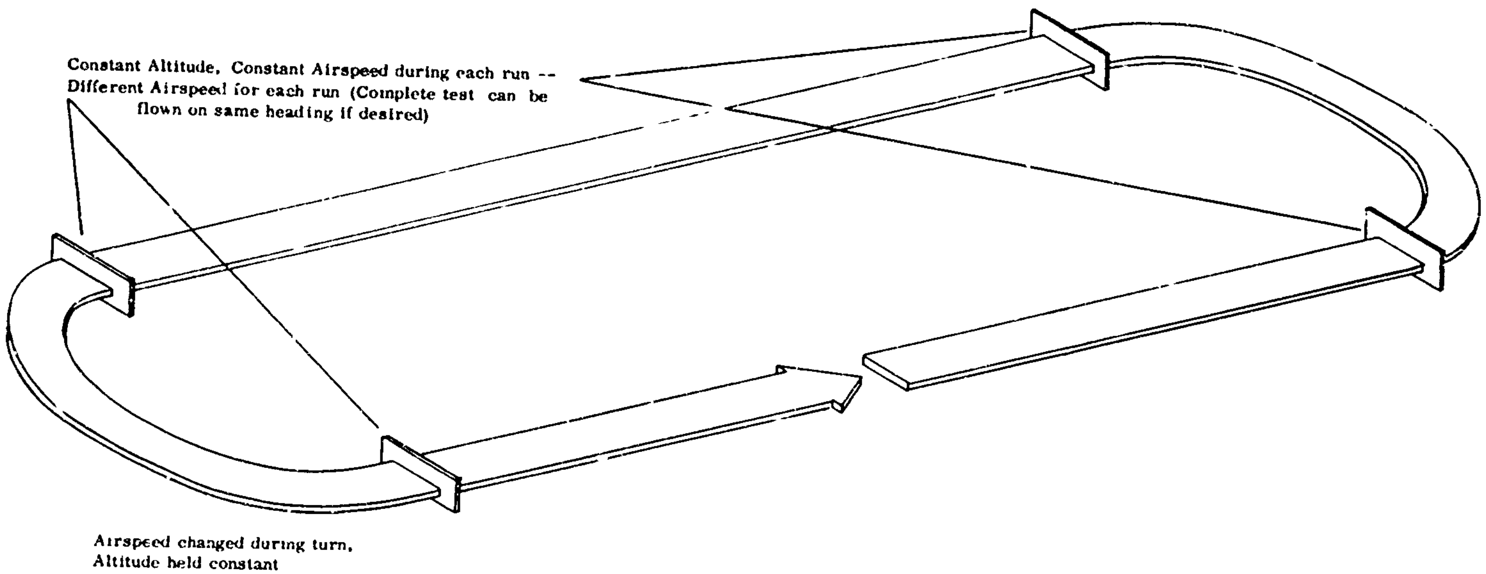

Figure 7.1

Typical Flight Pattern for Trailing Cone Flight Calibration Method

7.2 AIRBORNE TEST INSTRUMENTATION

Flight test equipment for the aircraft is listed below. The equipment is monitored and data is recorded by a qualified observer, or the pilot in the case of a single place aircraft. A qualified observer is defined as an experienced engineer, pilot, instrument mechanic or person familiar with the special instruments being recorded and the procedures described in this section.

(1) Trailing Cone Assembly: An approved cone assembly is installed on the test aircraft. Examples of trailing cones are given in References 36, 39, and 40. The assembly consists of a length of flexible hollow tubing with a nonlifting drag cone at the end. Internal diameter of the tubing should be 0.100 inch or larger and outside diameter should be about 0.250 inch. A steel tubing, about 2 feet long, is "spliced" into the flexible tubing and contains the static ports. The static ports are centered with about one foot of steel tubing on either side of the static ports location. This steel tube insures surface smoothness and uniformity in the vicinity of the static ports. The static ports are located about 10 to 15 feet ahead or 10 cone diameters ahead of the cone. A high strength steel wire or cable, about 1/16 inch diameter, through the length of the flexible tubing is used to carry the drag load of the cone. Some trailing cone systems are being used that consist of 3/8 inch O.D. plastic tubing with no center steel wire. The size and shape of the trailing cone is designed to provide the required drag tension over the flight test Mach number range.

The method of attachment of the trailing cone assembly to the aircraft depends on the aircraft type. A take-up reel can be used on some aircraft to extend and retract the tubing and cone in flight. On some aircraft it is possible to use a fixed length trailing cone assembly and to drag the cone on the ground behind the aircraft during take-off and landing. Preferred mounting location for the trailing cone assembly is at the top of the vertical stabilizer of the aircraft.

(2) Differential Pressure Gage: An accurate, small range differential pressure gage is installed at the observer's

station in the aircraft. The type specified on Section 3 of Appendix A is acceptable. The unit shall be calibrated within the preceding 10 days. The gage should be capable of withstanding overpressures of at least 25 inches Hg, for pressure checking purposes. The gage should also have a small internal volume to minimize pressure lag. Signal from the pressure gage is displayed on a meter for visual observation by the flight observer. A calibrated test signal should be provided to check full scale range of the visual meter. A DC signal adequate to drive a voltage recorder or a galvanometer (Item 5) directly can also be used to obtain a continuous recording of the differential pressure.

(3) Airspeed Indicator: A precision airspeed indicator with a certified scale error correction and repeatability accuracy of ± 2.5 knots is installed at the flight observer's station. The indicator is to be selected for low hysteresis and good stability and repeatability, and certified within the preceding 30 days. (The barometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate with corrections, to within 0.005 inch Hg). A calibration chart of airspeed indicator instrument correction (ΔV_{ic}) versus indicated airspeed (V_i) is needed with the airspeed indicator for use in data reduction.

If the pilot's primary airspeed indicator meets the above requirements and is not compensated for position error by an air data computer, it can be used in lieu of a special indicator installed at the flight observer's station.

(4) Altimeter: A calibrated altimeter is installed at the flight observer's station. The altimeter is selected to have good stability and repeatability, low hysteresis, and small temperature dependency. A precision altimeter (calibrated to ± 20 feet or 0.25%, whichever is greater) should be used on all jet aircraft and is recommended for other aircraft. The unit is to be calibrated within the preceding 30 days and meet the requirements of the latest FAA Technical Standard Order on altimeters. (The barometer used as a reference for calibration shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg, References 14 and 41). A calibration

chart of altimeter instrument correction (ΔH_{ic}) versus uncorrected altimeter reading (H_i) is needed with the altimeter for use in data reduction. The calibration and operation of the special altimeter shall be at a setting of 29.92 (inches Hg).

If the pilot's primary altimeter meets the above requirements and is not compensated for position errors by an air data computer, it can be used in lieu of the special altimeter installed at the flight observer's station.

(5) Recording Oscillograph: An airborne recording oscillograph, or photopanel, gives an automatic and continuous recording of flight parameters and could be used in the test aircraft. It would replace the special airspeed indicator, Item (3), and the special altimeter, Item (4), at the observer's station.

An oscillograph can also be used to record pressure differential accurately from the pressure gage, Item (2). To obtain the desired resolution, 12" oscillograph is recommended. At least 10 inches of the 12-inch trace width should represent the differential pressure range of the pressure gage. The recording of compressible dynamic pressure (q_{cm}), for airspeed, and absolute static pressure (p_m), for altitude, on the oscillograph trace can be obtained using multi-sweep pressure transducers of the SFIM type (Reference 27) or equivalent. The SFIM transducers give a continuous trace of these parameters and can be used to detect variations* in airspeed and altitude immediately before and after a calibration point, as well as to obtain the exact value of q_{cm} and p_m at the calibration point.

A time recording is desirable on the galvanometer trace. If not available, the flight observer can mark the film with a spare trace channel and record the film footage number when a calibration point is taken.

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*Variation in q_{cm} and p_m at the test condition could introduce pressure lag errors in the measured pressures and cause rejection of the data at the test point.

Angle of attack (α), and possibly angle of sideslip (β), traces on the oscillograph might also be desirable in lieu of visually recorded meter, Item (6) below.

The recording oscillograph should be laboratory calibrated at the same time as the differential pressure gage (Item 2), to determine conversion constants and any nonlinearity of the trace signals.

(6) Angle of Attack Meter: Position errors for static pressure port installations, especially flush fuselage installations, on some aircraft can vary appreciably with angle of attack of the aircraft. Obtaining the relationship of position error with changing angle of attack could be desirable. Incorporation of angle of attack in the presentation of flight test data is included in Section 8. The primary angle of attack sensor of the aircraft should be used. The pilot's angle of attack meter can be read or a meter installed at the observer's station in the aircraft. Output signals from some angle of attack sensors can also be recorded directly on a recording oscillograph, Item (5).

(7) Voice Communication: Voice communication is needed between the aircraft's pilot and flight observer.

7.3 FLIGHT TEST PROGRAM

7.3.1 Prior-to-Flight Procedure

The following installations are to be made in the aircraft prior to flight test.

(1) The "Trailing Cone" assembly is installed in the aircraft. Preferred mounting location is from the top of the vertical stabilizer. A flexible noncollapsible tubing with an internal diameter of about 0.305 inch is installed in the aircraft between the trailing cone assembly and the flight observer's station in the aircraft. The tubing transmits static pressure from the trailing cone to the differential pressure gage. Tubing length should be as short as possible.

(2) "T"-shaped pressure fittings are placed in the primary static pressure and pitot pressure lines of the aircraft. Special tubings are used between each "T" and the differential pressure gage (and altimeter and airspeed indicator or oscillograph) mounting location in the aircraft. The tubing length should be as short as possible. Flexible, noncollapsible plastic tubing is permissible if the installation is not permanent. The static pressure tubing should have an internal diameter of about 0.305 inch and the pitot pressure tubing should have an internal diameter of about 0.180 inch. The "T" fittings can be made permanent installations on the aircraft and are to be disconnected from the special tubing and capped when not used for calibration flights.

(3) The special altimeter and airspeed indicator, or recording oscillograph, are placed at the observer's station in the aircraft. Altitude and airspeed pressure transducers are connected to the special pitot and static pressure tubings. A second "T" pressure fitting is placed in the static pressure line to allow connection to the differential pressure gage.

(4) The differential pressure gage is placed at the observer's station and connected to the aircraft's static pressure line and trailing cone pressure line.

(5) After insertion of the differential pressure gage and special altitude and airspeed pressure transducers, the aircraft's primary pitot and static pressure lines are sealed and pressure checked with an airspeed system field check unit. With the source of vacuum isolated, the recommended maximum allowable leak rate for the complete static pressure system over a period of 5 minutes is twenty (20) feet/min, at an initial pressure altitude of 30,000 feet*. If the range of the pilot's altimeter does not have a calibrated range of 30,000 feet, a pressure sufficient to produce 3/4 of full scale deflection on the altimeter shall be applied.

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*The differential pressure gage should be able to withstand overpressure of at least 25 inches Hg.

With the source of pressure isolated, the maximum allowable leak rate for the complete pitot pressure system of the test aircraft over a period of 5 minutes is 2 knots/minute at the maximum airspeed attainable with the aircraft.

Static pressure ports on the trailing cone assembly are connected to the airspeed system field check unit. With the source of vacuum isolated, the maximum allowable leak rates over a period of 5 minutes is twenty (20) feet/minute at an initial pressure altitude of 30,000 feet.

7.3.2 Flight Calibration of Trailing Cone Assembly

Measuring true static pressure in flight is fundamental to the Trailing Cone Flight Calibration Method. Distance of the static ports behind the aircraft, needed to obtain true static pressure, must be known. Once this distance is determined for an aircraft type, and configuration, it should remain the same for all additional test aircraft of the same type and configuration, provided the same trailing cone assembly design is used.

Static pressure measured by the Trailing Cone is greater than true static pressure for distances close behind the aircraft and, in most instances, asymptotically approaches true static pressure with increasing distance behind the aircraft. In determining the required trailing distance, could be 100 feet or more, the flight test aircraft can use a take-up reel to extend and retract the trailing cone in flight. At a constant airspeed and altitude, the trailing cone is extended in increments and pressure differential between the trailing cone and the aircraft's primary static pressure system is measured at each increment. In most instances, true static pressure will be sensed by the static ports on the trailing cone assembly when the pressure differential no longer changes with increasing distance behind the aircraft. This method is explained briefly in References 36 and 39.

Distance of static ports behind the aircraft at which true static pressure is measured could vary with airspeed, altitude, and aircraft configuration, i.e. clean or with flaps, landing gear, external stores, etc. Tests should be conducted over the airspeed-altitude flight envelope of the aircraft for the various aircraft configurations to determine the minimum

length needed for the trailing cone assembly. This length can then be specified as the required length of static ports behind an aircraft type and used for calibration of subsequent aircraft of the same type.

There is evidence, Reference 36, that for certain aircraft configurations, pressure measured by the trailing cone assembly will not revert to true static pressure as the distance from the aircraft is increased. This may be caused by a pressure field formed by trailing vortices from wing tips or extended flaps. To verify that static pressure sensed by the trailing cone assembly is actually true static pressure, the assembly should be calibrated using one or more of the other three methods, "Camera Fly-Over", "Pacer", or "Radar Tracking", described previously in this report. This need be done only on the first aircraft, used for calibration of the trailing cone assembly as explained in the preceding paragraphs. If a small, and consistent, static pressure error does exist in the cone sensed pressure, and if the error is precisely known, it can be corrected for in data reduction.

7.3.3 Flight Test Coordination and Pilots Orientation

The flight observer in the test aircraft is responsible for coordination of the flight test program. (If the flight observer is not completely qualified, the flight test engineer must coordinate the program). The observer should be familiar with the operational manual of the aircraft under test. He must brief the pilot before the flight begins on all applicable parts of the following Section 7.3.4. Paragraph (4) which requires level, unaccelerated flight while data is being taken is especially important for the pilot to understand. Examples of check lists for the pilot and flight observer are given in Sections 7.3.5 and 7.3.6.

The flight test observer also makes out a flight test plan for himself and the pilot which states each test point required and the sequence of tests. Forms 7-1 and 7-2 are examples of data cards which could be prepared by the flight observer.

The number of data points required at altitude will depend on the type of test aircraft. The flight observer should review the operational manual for the test aircraft to determine the number of test points necessary for new certification or recalibration. The following applies to original calibration of the airspeed system following construction or major overhaul or modification to the airframe. At least five test points with gear and flaps retracted are needed at each altitude, including:

(a) Minimum safe speed.
(b) Maximum safe subsonic Mach number.
(c) Three or more different intermediate speeds between minimum and maximum safe speeds. (Additional points will be needed if flight extends supersonic).

A minimum of three data points should be taken at each test point. Tests should be conducted at three or more altitudes covering the operation range of the aircraft to determine dependence of static pressure position error on changing angle of attack or aircraft gross weight.

At the lowest test altitude, 5,000 to 10,000 feet, the following aircraft configurations should be included in the test program.

(a) Normal landing configuration with gear and flaps extended.
(b) Normal approach configuration with gear and flaps extended.
(c) Normal approach configuration with gear retracted.

For each configuration, test at three different speeds which cover the safe operational limits of the aircraft. A minimum of three data points should be taken at each airspeed test point.

For recalibration check of an aircraft previously calibrated (those having calibration cards or graphs for the static pressure system) it should only be necessary to conduct an abbreviated test. The flight observer should check the flight operational manual and test objectives for requirements.

The tests should be conducted under non-turbulent atmospheric conditions (smooth air). Consideration should be given to conducting tests in the early part of the day, from about 3:00 A.M. to 8:00 A.M., and over large bodies of water or constant color terrain. It might be necessary for the test aircraft's pilot to search for smooth air during the testing period. Daylight is not needed for flying with the trailing cone and the early pre-dawn hours will probably give the smoothest atmospheric conditions.

7.3.4 Flight Test Procedure

The complete flight test procedure for the "Trailing Cone" calibration method is described below. It is assumed that a special altimeter and a special airspeed indicator are installed at the flight observer's station, and that a visual meter is used to obtain readings from the special differential pressure gage.

It is also assumed that the trailing cone assembly has been calibrated as explained in Section 7.3.2 and distance of the static ports behind the aircraft, needed to obtain true static pressure, is known.

(1) The pilot takes off and flies to the first test altitude. The flight observer activates the special differential pressure gage and performs any necessary in-flight calibration of the visual meter for the pressure gage.

(2) At the test altitude, the pilot stabilizes on the first test airspeed. The observer's altimeter and airspeed indicator, both corrected for scale error, are used to establish the test condition. The flight observer directs the pilot to the approximate airspeed and altitude and the pilot then uses his altimeter and airspeed indicator readings to maintain this condition. After the airspeed has been established, the pilot maintains constant power setting. Control surface movements should be minimized. The use of autopilot is recommended for stabilization of large jet transports.

(3) The flight observer makes any necessary final calibration adjustments of the visual differential pressure meter.

(4) With the pilot maintaining level, unaccelerated flight, the observer records:

(a) Differential pressure reading of visual meter.
(b) Special altimeter and airspeed indicator readings.
(c) Angle of attack and/or aircraft gross weight.

All readings should be taken rapidly.
NOTE: The differential pressure meter must be stable for at least 10 seconds before the time of reading because of pressure lag inherent in the long static pressure lines used with the trailing cone assembly. The trailing cone is also sensitive to control surface movements and control surfaces should be held stable while data is being recorded.

(5) Steps (2), (3), and (4) are repeated for each airspeed calibration point at the test altitude. A recommended sequence is to calibrate at interval from the lowest to the highest airspeed and then calibrate at the same airspeed points while decreasing airspeed. This increasing then decreasing airspeed sequence should be repeated a minimum of two times at each altitude.

(6) Steps (2) through (5) are repeated for each test altitude, and each aircraft configuration.

(7) Data reduction and determination of static pressure position error of the test aircraft is outlined in detail in Section 8.

7.3.5 Check List For Flight Observer in Test Aircraft

A. Special Airborne Equipment

1) Trailing Cone Assembly
2) Special Differential Pressure Gage
3) Airspeed Indicator
4) Altimeter
5) Voice Communication Equipment

Optional Airborne Equipment

1) Recording Oscillograph
2) Angle of Attack Meter

B. Aircraft Installations

1) Install Special Airborne Equipment, Items 1 thru 5, above.
2) Leak check pitot pressure, static pressure, and cone pressure systems.

C. Prior-To-Flight

1) Determine test points required (check aircraft operational manual).
2) Obtain calibration data for trailing cone assembly and differential pressure gage.
3) Determine method for obtaining gross weight of aircraft.
4) Fill out data cards and flight test plan (Forms 7-1 and 7-2).
5) Coordinate flight with test pilot and have a thorough preflight briefing with him.

D. Flight (Record at each test point).

1) Differential Pressure Gage Meter reading.
2) Special Altimeter reading.
3) Special Airspeed Indicator reading.
4) Gross weight information.
5) Time

E. Post Flight

1) Gather all data cards and test sequence card of pilot.
2) Reduce data using Forms 8-5 in Section 8.

7.3.6 Check List For Test Pilot

1) Pre-flight briefing with flight observer.
2) Review pilot's test sequence card (Form 7-1).
3) All test data must be taken while flying through smooth air (non-turbulent atmospheric conditions).
4) At each test point maintain constant power setting and constant altimeter reading.
5) Minimize control surface movements before and during test point.
6) Maintain level, unaccelerated flight until all data, at each test point, has been recorded by flight observer. (About 15 to 20 seconds).

FORM 7-1

TEST SEQUENCE CARD FOR PILOT OF TEST AIRCRAFT

(Fill In Before Tests Begin)

Date: 25 JUNE, 196[illegible]
Aircraft Type: REC 525 Z
Aircraft Number: Y 2013 Z
Pilot: JOHN D DOE

(Filled in with sample data)

Test Point	Aircraft Config.	Test Altitude (xx,xxx.) Feet	Test Airspeed (xxx.) Knots	Remarks
1	CLEAN	10,000	200	
2			260	
3			320	
4			380	
5			440	
6			440	
7			3[illegible]0	
8			320	
9			26[illegible]	
10			200	
11			200	
12			260	
13			320	
14			380	
15			440	
16	PARTIAL FLAPS	10,000	160	20° FLAPS
17			90	
18			220	
19			220	
20			190	
21			160	
22			160	
23			190	
24			220	

FORM 7-2

DATA CARD FOR FLIGHT OBSERVER

Date: 25 JUNE, 96[illegible]
Aircraft Type: REC 525 Z
Aircraft Number: Y2010 Z
Data Taken By: JOHN J. JONES

(Filled in with sample data)

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)					
Test Point	Aircraft Config.	Test Altitude (xx,xxx.) Feet	Test Airspeed (xxx.) Knots	Meter Reading (xxx.)	Altimeter Reading (xx,xxx.) Feet	Airspeed Reading (xxx.) Knots	Gross Weight (xxx,x00) Lbs	Time	Remarks
1	CLEAN	10,000	200	-21	9,9[illegible]5	19[illegible]	205,300	5:[illegible] AM	
2			260	-2[illegible]	9,955	2[illegible]		:2[illegible]	
3			320	-40	9,[illegible]	3[illegible]		:28	
4			380	[illegible]	9,950	3[illegible]		:30	
5			44[illegible]	-72	9,94[illegible]	44[illegible]		:35	
6			440	-10	9,9[illegible]	44[illegible]	204,200	5:45	
7			380	-64	9,970	[illegible]		:49	
8			320	-57	9,94[illegible]	322		:[illegible]	
9			260	-39	9,92[illegible]	263		:[illegible]	
10			[illegible]	-21	9,910	200		:[illegible]	
11			20[illegible]	-26	9,910	199	202,[illegible]	[illegible]	
12			2[illegible]	-3[illegible]	9,9[illegible]	2[illegible]		:59	
13			32	-54	9,940	318		6:02	
14			[illegible]	-71	9,935	382		:0[illegible]	
15			440	-23	9,945	445		:09	
16	PARTIAL FLAPS	10,000	1[illegible]	-22	9,96[illegible]	15[illegible]	201,[illegible]	[illegible]	
17			19[illegible]	-31	9,94[illegible]	19[illegible]		:[illegible]	
18			2[illegible]	-42	9,9[illegible]	21[illegible]		:[illegible]	
19			220	-45	9,94[illegible]	[illegible]	200,500	6:[illegible]	
20			19[illegible]	-32	9,9[illegible]	191		:[illegible]	
21			160	-21	9,9[illegible]	152		:32	
22			160	-22	9,940	154	199,[illegible]00	6:[illegible]	
23			190	-40	9,925	189		:36	
24			220	-45	9,950	221		:39	

SECTION 8

FLIGHT TEST DATA REDUCTION, ANALYSIS, AND FINAL PRESENTATION

8.1 FLIGHT TEST DATA REDUCTION FORMS

Step-by-step data reduction procedures are presented in this section for each of the four static pressure flight calibration methods described in Sections 4, 5, 6, and 7. The forms are listed in the following order:

FORM	TITLE	REFERENCED SECTION
8-1	Camera Fly-Over Method (Full Range Altimeter in Test Aircraft)	4.5
8-2	Camera Fly-Over Method (Static Port Calibrator in Test Aircraft)	4.6
8-3	Pacer Aircraft Calibration Method	5
8-4	Radar Tracking Calibration Method	6
8-5	Trailing Cone Calibration Method	7

The forms describe in detail the complete data reduction procedure for each of the flight calibration methods. A brief description is included for each parameter and each step. The number of significant places needed for each parameter is shown in the dimension column. Because each calibration method can be used for all airplanes, regardless of speed and altitude capabilities, each data reduction form includes spaces for gross weight of the aircraft (W), Mach number (M_m), angle of attack (α), and angle of sideslip (β). These parameters may or may not be desired for a particular application.

The forms are designed for use in making up abbreviated data forms to cover reduction of multiple data points. These multiple data forms can be arranged according to personal preference of the personnel responsible for data reduction.

An example, for the trailing cone flight calibration method, is included as Figure 8.3. The steps, identified by symbol only, are arranged in columns across the data sheet and there is one row per data point.

An example of data evaluation and final presentation is included below in Section 8.2. Flight test data points should be presented in the form of static pressure error ($\Delta p/q_{cm}$) as a function of measured airspeed (V_m) for low speed data and $\Delta p/q_{cm}$ as a function of measured Mach number (M_m) for high subsonic, transonic, and supersonic data. Dependency of static pressure error on changing angle of attack or aircraft gross weight, at constant V_m or M_m, should be investigated.

8.2 EXAMPLE OF ANALYSIS AND PRESENTATION OF FLIGHT TEST DATA

An example of a complete flight test calibration for static pressure position error, from raw data cards to final altimeter correction cards, is presented in this section. The "Trailing Cone" method of flight calibration, described in Section 7, was chosen and is representative also of procedures that would be used for the other three methods: Camera Fly-Over, Pacer Aircraft, and Radar Tracking.

8.2.1 Flight Data Cards

Examples of Test-Sequence Cards for the test pilot and data cards for the flight observer are given in Figures 8.1 and 8.2. They correspond to Forms 7-1 and 7-2 from Section 7. The forms are filled out with a representative test sequence for an altitude of 10,000 feet. An example of data that would be taken by the flight observer is included.

8.2.2 Data Reduction Forms

A filled out data reduction form is shown in Figure 8.3. The form corresponds to Form 8-5 and has been adapted to accept multiple data points. Each step has been identified by a symbol designation. The "raw" data tabulated in Figure 8.2 was reduced into the final form of static pressure error ($\Delta p/q_{cm}$) as a function of measured airspeed (V_m) and measured Mach number (M_m). For aircraft with flight capabilities below $M = 0.6$ and

20,000 feet altitude the determination of M_m might not be necessary.

8.2.3 Plotting of Final Data

Static pressure position error is shown as a function of measured airspeed (V_m) on Figure 8.4 and as a function of Measured Mach number (M_m) on Figure 8.5. Data was taken from the data reduction forms, Figure 8.3. Each data point is plotted and different symbols are used for each aircraft configuration. Only one gross weight and one altitude are shown. The data maintained a constant $\Delta p/q_{cm}$ value with airspeed up to V_m = 350 knots (Mach number M_m = 0.6) in the clean configuration and a constant $\Delta p/q_{cm}$ when the aircraft's flaps and gear were extended. This tends to indicate insensitivity of the static pressure error to changes in aircraft gross weight or angle of attack and is representative of a good static pressure system on an aircraft. Compressibility influences, possibly due to close proximity of static pressure ports to the aircraft's wing, make $\Delta p/q_{cm}$ more positive at the higher Mach numbers.

Faired curves are drawn through the data points. The data is not biased toward singular "stray" data points which most possibly are in error. Extreme care must be taken in properly fairing curves through the data points. Persons fairing the data should have an engineering background and be well acquainted with the information presented in Section 2 of this report. The faired curves can be used directly as the air data computer corrections for static pressure error.

8.2.4 Determination of Altitude Correction

Static pressure position errors, from the faired curves on Figures 8.4 and 8.5, have been converted to pressure altitude correction on Figures 8.6 and 8.7. Altitude corrections (ΔH_c) and measured altitude (H_m) are determined for nominal true altitudes (H), measured airspeeds (V_m), and measured Mach number (M_m) covering the flight capabilities of the aircraft, for all aircraft configurations. The altitude correction $\Delta H_c = H - H_m$, is calculated from static pressure error, $\Delta p = p_m - p$, using the relationships found on Chart D-I. The example on Figure 8.6 determines ΔH_c as a function of V_m and H. Obtaining ΔH_c as a

function of M_m and H is described in Figure 8.7; this relationship should not be necessary for low speed aircraft.

8.2.5 <u>Altimeter Correction Cards</u>

Altimeter position error correction cards contain values of altitude position error correction (ΔH_c) or measured altitude ($H_m = H - \Delta H_c$) as a function of the altitude (H) and measured airspeed (V_m) or Mach number (M_m). They are used by the pilot to correct the altimeter reading to true pressure altitude (H). An example of a correction card is shown on Figure 8.8. The filled-in numbers correspond to values obtained from Figures 8.6 and 8.7. The correction card represents the complete operational range of the aircraft. Altitude corrections for low speed flight and for take-off, loiter, approach, and landing aircraft configurations are presented as a function of measured airspeed (V_m). Altitude corrections for high speed cruise conditions are presented as a function of measured Mach number (M_m).

FORM 8-1

CAMERA FLY-OVER METHOD USING A FULL RANGE
ALTIMETER IN THE TEST AIRCRAFT

(See Section 4.5)

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Prepared By:

A. Common Parameters Throughout Run (See Figure 4.5)

Step	Description	Parameter	Value (Fill In)	Dimension*
1	Camera lens elevation above test site.	h_1	+	(x.x) Ft
2	Wing tip elevation above run-up pad.	h_2	+	(x.x) Ft
3	Estimated wing tip deflection in flight.	Δh_2	+	(x.x) Ft
4	Elevation of run-up pad minus elevation of camera test site.	h_3		(x.x) Ft
5	Correction Factor: (2)+(3)+(4)-(1)	Δh_c	+	(x.x) Ft
6	Measured wing span.	b		(x.x) Ft
7	Average focal length of camera (See Section 4.4).	f		(x.xxx) In.

* "x"-values in parentheses denote significant places required for values, i.e., (x.x) feet means dimension in feet rounded off to nearest 0.1 foot.

Form 8-1

B. Initial Values Before Tests (See Section 4.5.3(2))

Step	Description	Parameter	Value (Fill In)	Dimension
8		Date		
9	Time of day of initial readings.	Time	______	
10	Initial altimeter reading for test aircraft.	$(H_i)_{Ao}$	______	(xxxx.) Ft**
11	Instrument correction for altimeter.	$(\Delta H_{ic})_{Ao}$		(xx.) Ft
12	(10)+(11): Corrected initial altimeter reading.	$(H_m)_{Ao}$		(xxxx.) Ft
13	Initial altimeter reading at test site.	$(H_i)_{Bo}$	______	(xxxx.) Ft
14	Initial temperature reading at test site.	T_{Bo}	______	(xx.)°F
15	(14) + 460.	T_{Bo}		(xxx.)°R

** All altimeter readings to nearest 5 feet.

C. Final Values After Tests (See Section 4.5.3(6))

Step	Description	Parameter	Value (Fill In)	Dimension
16	Time of day of final readings.	Time	______	
17	Final altimeter reading for test aircraft.	$(H_i)_A$	______	(xxxx.) Ft
18	Final altimeter reading at test site.	$(H_i)_B$	______	(xxxx.) Ft
19	(17)-(10), Barometric pressure-altitude change during run.	$(H_i)_A - (H_i)_{Ao}$		(xx.) Ft
20	(18)-(13), Barometric pressure-altitude change during run.	$(H_i)_B - (H_i)_{Bo}$		(xx.) Ft
21	(19)-(20), if larger than ± 10 feet suspect instability of one or both altimeters.			(xx.) Ft
22	Final temperature reading at test site.	T_B	______	(xx.) °F

Form 8-1

D. D... Reduction For Each Test Point (See Section 4.5.3)

Step	Description	Parameter	Value (Fill In)	Dimension
23	Time of day when data was recorded.	Time	______	
24	Clean, or with flaps, gear, etc. extended.	Configuration	______	
25	Altimeter reading for test aircraft.	$(H_i)_A$	______	(xxxx.) Ft
26	Instrument correction for altimeter.	$(\Delta H_{ic})_A$		(xx.) Ft
27	(25)+(26), corrected altimeter reading.	$(H_m)_A$		(xxxx.) Ft
28	Pressure corresponding to pressure-altitude $(H_m)_A$, From Chart D-4.	P_m		(xx.xxx)"Hg
29	Airspeed indicator reading for test aircraft.	$(V_i)_A$	______	(xxx.) Knts
30	Instrument correction for airspeed indicator.	$(\Delta V_{ic})_A$		(xx.) Knts
31	(29)+(30), corrected airspeed indicator reading.	$(V_m)_A$	-------	(xxx.) Knts
32	Altimeter reading at test site.	$(H_i)_B$	______	(xxxx.) Ft
33	(27)-(13) pressure altitude change from initial reading.	$(H_i)_B - (H_i)_{Bo}$		(xx.) Ft
34	(12)+(33), corrected base pressure altitude of test aircraft.	H_B		(xxxx.) Ft
35	Base pressure corresponding to H_B, from Chart D-4.	P_B		(xx.xxx)"Hg
36	Film image of aircraft's wing span.	b_i		(x.xxx) in.
37	(6)x(7)/(36), elevation of wing tips above camera.	$\Delta h_o = f(\frac{b}{b_i})$		(xxx.) Ft
38	(37)-(5)	$\Delta h_{oc} = \Delta h_o - \Delta h_c$		(xxx.) Ft
39	Temperature reading at test site.	T_B	______	(xx.) °F
40	(39) + 460.	T_B		(xxx.) °R
41	(38)/(40).	$\Delta h_{oc}/T_B$		(x.xxx) $\frac{ft}{°R}$
42	From (41) and Chart D-2, Curve 1	$(p-p_B)/p_B$		(.xxxxx)
43	(42) x (35).	$p-p_B$		(x.xxx)"Hg
44	(43) + (35).	p		(xx.xxx)"Hg

Form 8-1

D. Continued.

Step	Description	Parameter	Value (Fill In)	Dimension
45	(28) - (44), Calculated static pressure position error.	$\Delta p = p_m - p$		(x.xxx)"Hg
46	From (31) and Chart D-3.	q_{cm}		(x.xxx)"Hg
47	(45)/(46).	$\Delta p/q_{cm}$	------	(.xxxx)

Form 8-2

CAMERA FLY-OVER METHOD USING A STATIC
PORT CALIBRATOR IN THE TEST AIRCRAFT

(See Section 4.6)

Date:
Aircraft Type:
Aircraft Number:
Test Site:
Prepared By:

A. Common Parameters Throughout Run (See Figure 4.5)

Step	Description	Parameter	Value (Fill In)	Dimension*
1	Camera lens elevation above test site	h_1	+	(x.x) Ft
2	Wing tip elevation above run-up pad.	h_2	+	(x.x) Ft
3	Estimated wing tip deflection in flight.	Δh_2	+	(x.x) Ft
4	Elevation of run-up pad minus elevation of camera test site.	h_3		(x.x) Ft
5	(2)+(3)+(4)-(1), correction factor.	Δh_c	+	(x.x) Ft
6	Measured wing span.	b		(x.x) Ft
7	Average focal length of camera (See Section 4.4).	f		(x.xxx) In.
8	Calibrated full-scale signal of calibrator (See Appendix A).	$(\Delta p)_{fs}$		(.xxx)"Hg

*-"x" Values in parentheses denote significant places required for value, i.e., (x.x) ft means dimension in feet rounded off to nearest 0.1 foot.

Form 8-2

B. Initial Values Before Tests (See Section 4.6.3(3))

Step	Description	Parameter	Value (Fill In)	Dimension
9		Date		
10	Time of day of initial readings.	Time	____	
11	Initial barometer reading at test site.	P_{Bo}	____	(xx.xxx)"Hg
12	Initial temperature reading at test site.	T_{Bo}	____	(xx.)°F
13	(12) + 460.	T_{Bo}		(xxx.)°R
14**	Zero with trapped sample minus calibrate zero (width between trace lines on oscillograph). If zero, omit steps (15) and (16).	ΔX	____	(.xx) In.
15	Calibrate full-scale minus calibrate zero (width between trace lines on oscillograph).	ΔX_c	____	(x.xx) In.
16	(8)x(14)/(15), reference zero for calibrator. Value is zero if ΔX is zero.	$(\Delta p)_o$		(.xxx)"Hg

C. Final Values After Tests (See Section 4.6.3(8))

Step	Description	Parameter	Value (Fill In)	Dimension
17	Time of day of final readings.	Time	____	
18	Final barometer reading at test site.	P_B	____	(xx.xxx)"Hg
19	Final temperature reading at test site.	T_B	____	(xx.)°F
20**	Zero with trapped sample minus calibrate zero (width between trace lines on oscillograph). If zero, omit steps (21) and (22).	ΔX	____	(.xx) In.
21	Calibrate full-scale minus calibrate zero (width between trace lines on oscillograph).	ΔX_c	____	(x.xx) In.
22	(8)x(20)/(21), reference zero for calibrator plus barometer change.	$(\Delta p)_f$		(.xxx)"Hg

**Value entered must be corrected for any nonlinearity error, as explained in Appendix A.

Form 8-2

C. Continued.

Step	Description	Parameter	Value (Fill In)	Dimension
23	(22)-(16), Indication of barometer change.	$(\Delta p)_f - (\Delta p)_o$		(.xxx)"Hg
24	(18)-(11), Station barometer change.	$p_B - p_{Bo}$		(.xxx)"Hg
25	(23)-(24), If larger than ±0.005" Hg suspect instability in either calibrator's signal or ground barometer.			(.xxx)"Hg

Form 8-2

D. Data Reduction For Each Test Point (See Section 4.6.3)

Step	Description	Parameter	Value (Fill In)	Dimension
26	Time of day when data was recorded.	Time	_____	
27	Clean, or with flaps, gear, etc., extended.	Configuration	__ __	
28	Barometer reading at test site.	p_B	_____	(xx.xxx)"Hg
29	(28)-(11), Barometer change.	$p_B - p_{Bo}$		(.xxx)"Hg
30	Temperature reading at test site.	T_B	_____	(xx.)°F
31	(30) + 460.	T_B		(xxx.)°R
32	Film image of aircraft's wing span.	b_i	_____	(x.xxx) In.
33	(6) x (7)/(32).	$\Delta h_o = f(\frac{b}{b_i})$		(xxx.) Ft
34	(33) - (5).	$\Delta h_{oc} = \Delta h_o - \Delta h_c$		(xxx.) Ft
35	(34)/(31).	$\Delta h_{oc}/T_B$		(x.xxx)ft/°R
36	From (35) and Chart D-2, Curve 1.	$(p-p_B)/p_B$		(.xxxxx)
37	(36) x (28).	$p - p_B$		(x.xxx)"Hg
38*	Calibrator's signal trace minus calibrate zero trace (width between trace lines on oscillograph).	ΔX	_____	(x.xx) In.
39	Calibrate full-scale minus calibrate zero (width between trace lines on oscillograph).	ΔX_c	_____	(x.xx) In.
40	(8)x(38)/(39), uncorrected pressure differential of calibrator.	$(\Delta p)_{uc}$		(x.xxx)"Hg
41	(40)-(16), corrected pressure differential of calibrator.	$p_m - p_{Bo}$		(x.xxx)"Hg
42	(41)-(37)-(29), calculated static pressure error.	$\Delta p = p_m - p$		(x.xxx)"Hg
43*	Pitot pressure minus static pressure ($p_{t'm} - p_m$) from airspeed transducer in oscillograph.	q_{cm}	_____	(xx.xxx)"Hg
44	(42)/(43).	$\Delta p/q_{cm}$	-----	(.xxxx)
45**	Calibrated airspeed, from (43) and Chart D-3.	V_m	-----	(xxx.)Knots
46	(41) + (11).	p_m		(xx.xxx)"Hg

Form 8-2

D. Continued.

Step	Description	Parameter	Value (Fill In)	Dimension
47	Pressure altitude corresponding to P_m, from Chart D-4.	H_m		(xxxx.) Ft
48*	Gross weight of aircraft.	nW	____	(xxx,x00.) Lbs
49	(43) + (46), pitot pressure.	$P_{t'm}$		(xx.xxx)"Hg
50	(49)/(46).	$P_{t'm}/P_m$		(x.xxxx)
51	Mach number corresponding to $P_{t'm}/P_m$ from (50) and Table C-2.	M_m		(.xxx)
52***	Angle of attack.	α	____	(xx.x) degrees
53***	Angle of sideslip.	β	____	(xx.x) degrees

* Value entered must be corrected for any nonlinearity error, as explained in Appendix A.

**If airspeed indicator is used in lieu of airspeed transducer in oscillograph, q_{cm} in (43) will be obtained from V_m.

***Data reduction details to obtain parameter not included.

E. Data Reduction for Flight Observer's Meter

NOTE: The observer's meter on the calibrator should be recorded during the test runs. Reduction of some or all of the readings to pressure differential will prove useful as a check on the oscillograph readings. For low-speed, low-altitude flight, the meter can be set at a scale factor of (X1) or (X2) and the readings will be about as accurate as those obtained from the oscillograph.

When the meter data is reduced, the corresponding steps in Form 8-2 should be replaced with the values shown below.

Step	Description	Parameter	Value (Fill In)	Dimension
8	Calibrated pressure equivalent of units on Observer's Meter (See Appendix A).	Conversion constant		(.xxxxx)"Hg/ unit on meter
14*	Observer's meter on calibrator	Meter reading	____	(xxx.)
15	Selected scale factor for meter at time of reading.	Scale factor	1.	X(x.)
16	(8)x(14)x(15), reference zero for calibrator.	$(\Delta p)_o$		(.xxx)"Hg
20*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
21	Selected scale factor for meter at time of reading.	Scale factor	1.	X(x)
22	(8)x(20)x(21), reference zero for calibrator plus barometer change.	$(\Delta p)_f$		(.xxx)"Hg
38*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
39	Selected scale factor for meter at time of reading.	Scale factor	____	X(x.)
40	(8)x(38)x(39), uncorrected pressure differential of calibration.	$(\Delta p)_{uc}$		(.xxx)"Hg

*Value entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-3

PACER AIRCRAFT METHOD USING STATIC PORT CALIBRATORS IN BOTH PACER AND TEST AIRCRAFT

(See Section 5)

Date:
Test Aircraft Type:
Test Aircraft Number:
Pacer Aircraft Type:
Pacer Aircraft Number:
Test Location:
Prepared By:

A. Initial Values at Reference Airspeed (See Section 5.3.4)

Step	Description	Parameter	Value (Fill In)	Dimension
1		Date		
2	Time when pressure samples are sealed.	Time	___	
3	Clean, or with flaps, external stores, etc.	Test aircraft config.	___	
Readings From Pacer Aircraft				
4*	Observer's altimeter reading.	$(H_i)_o$	___	(xx,xxx.)Ft
5	Instrument correction for altimeter.	ΔH_{ic}		(xxx.) Ft
6	(4)+(5), corrected altimeter reading.	$(H_m)_o$		(xx,xxx.) Ft
7	Observer's airspeed indicator reading.	$(V_i)_o$	___	(xxx.) Knots
8	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.) Knots
	(7)+(8), corrected airspeed indicator reading.	$(V_m)_o$		(xxx.) Knots
10	From (9) and Chart D-3.	$(q_{cm})_o$		(xx.xxx)"Hg
11**	Angle of attack.	α	___	(xx.x)Degrees
12**	Gross weight of Pacer aircraft.	W	___	(xxx,x00)Lbs

* All altimeter readings to nearest 5 ft. Altimeters are at a setting of 29.92"Hg.

**Values may not be needed. Data reduction details to obtain parameters not included.

Form 8-3

A. Continued.

Step	Description	Parameter	Value (Fill In)	Dimension
13	Known position error of pacer aircraft for conditions (6) and (9), and possibly (11) or (12). (See Section 5.2.1).	$\left(\frac{p_m - p}{q_{cm}}\right)_o$	( )	(.xxxx)
14	(13) x (10).	$(p_m - p)_o$		(x.xxx)"Hg
15	Calibrated pressure equivalent of units on Observer's meter. (See Appendix A).	Conversion constant	( )	(.xxxxx)"Hg/ unit on meter
16*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
17	Selected scale factor for meter at time of reading.	Scale factor	1.	X(x.)
18	(15) x (16) x (17), reference zero for calibrator.	$(\Delta p)_o$		(.xxx)"Hg
Readings From Test Aircraft				
19	Pilot's altimeter reading.	$(H_i)_o$	____	(xx,xxx.)Ft
20	Instrument correction for altimeter.	ΔH_{ic}		(xxx.)Ft
21	(19)+(20), Corrected pilot's altimeter reading.	$(H_m)_o$	-------	(xx,xxx.)Ft
22	From (21) and Table C-I.	$(p_m)_o$	-------	(xx.xxx)"Hg
23	Pilot's airspeed indicator readings.	$(V_i)_o$	____	(xxx.)Knots
24	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.) Knots
25	(23)+(24), Corrected airspeed indicator reading.	$(V_m)_o$		(xxx.)Knots
26	From (25) and Chart D-3.	$(q_{cm})_o$		(xx.xxx)"Hg
27	Angle of attack.	α	____	(xx.x)Degrees
28	Gross weight of test aircraft.	W	____	(xxx,x00.)Lbs
29	Known position error of test aircraft for conditions (21) and (25), and possibly (27) or (28). (See Section 5.3.2).	$\left(\frac{p_m - p}{q_{cm}}\right)_o$	( )	(.xxxx)

*Value entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-3

A. Continued

Step	Description	Parameter	Value (Fill In)	Dimension
30	(29) x (26).	$(p_m-p)_o$		(x.xxx)"Hg
31	Calibrated pressure equivalent of units on Observer's meter. (See Appendix A).	Conversion constant	( )	(.xxxxx)"Hg/ unit on meter
32*	Observer's meter on calibrator.	Meter reading	____	(xx.)
33	Selected scale factor for meter at time of reading.	Scale factor	1.	X(x.)
34	(31)x(32)x(33), reference zero for calibrator.	$(\Delta p)_o$	-------	(.xxx)"Hg

B. Final Check Values at Reference Airspeed (See Section 5.3.4)

Step	Description	Parameter	Value (Fill In)	Dimension
	Time of Data Recording.	Time	____	
Readings From Pacer Aircraft				
35	Observer's altimeter reading.	$(H_i)_f$	____	(xx,xxx.)Ft
36	Instrument correction for altimeter.	ΔH_{ic}		(xxx.) Ft
37	(35)+(36), corrected altimeter reading.	$(H_m)_f$		(xx,xxx.)Ft
38	Observer's airspeed indicator reading.	$(V_i)_f$	____	(xxx.)Knots
39	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.) Knots
40	(38)+(39), corrected airspeed indicator reading.	$(V_m)_f$		(xxx.)Knots
41*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
42	Selected scale factor for meter at time of reading.	Scale factor	1.	X(x.)
43	(15) x (41) x (42).	$(\Delta p)_f$		(.xxx)"Hg
44	(43)-(18).	$(\Delta p)_f-(\Delta p)_o$		(.xxx)"Hg
45	Angle of attack.	α	____	(xx.x)Degrees
46	Gross weight of pacer aircraft.	W	____	(xxx,x00)Lbs

*Values entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-3

B. Continued

Readings from Test Aircraft

Step	Description	Parameter	Value (Fill In)	Dimension
47	Pilot's airspeed indicator reading, should be same as (23).	$(V_i)_f$	____	(xxx.)Knots
48	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.) Knots
49	(47)+(48), Corrected airspeed indicator reading.	$(V_m)_f$		(xxx.)Knots
50*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
51	Selected scale factor for meter at time of reading.	Scale factor	1.	X(x.)
52	(31) x (50) x (51).	$(\Delta p)_f$		(.xxx)"Hg
53	(52) - (34).	$(\Delta p)_f-(\Delta p)_o$		(.xxx)"Hg
54	(44)-(53), If greater than ± 0.005 inches Hg, suspect instability of pressures trapped in calibrators or a change of reference calibration for test aircraft, (29), with change in α or W.	Change from reference condition		(.xxx)"Hg
55	Angle of attack.	α	____	(xx.x)Degrees
56	Gross weight of test aircraft.	W	____	(xxx.x00)Lbs

C. Data Reduction For Each Test Point (See Section 5.3.4)

Step	Description	Parameter	Value (Fill In)	Dimension
57	Time of data recording.	Time	____	
58		Test aircraft config.		

Readings from Pacer Aircraft

Step	Description	Parameter	Value (Fill In)	Dimension
59	Observer's altimeter reading.	H_i	____	(xx,xxx.)Ft
60	Instrument correction for altimeter.	ΔH_{ic}		(xxx.)Ft
61	(59)+(60), corrected altimeter reading.	H_m		(xx,xxx.)Ft

*Values entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-3

C. Continued

Step	Description	Parameter	Value (Fill In)	Dimension
62	Observer's airspeed indicator reading.	V_i	———	(xxx.)Knots
63	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.)Knots
64	(62)+(63), Corrected airspeed indicator reading.	V_m		(xxx.)Knots
65	From (64) and Chart D-3.	q_{cm}		(xx.xxx)"Hg
66	Angle of attack.	α	———	(xx.x)Degrees
67	Gross weight of pacer aircraft.	W	———	(xxx,x00)Lbs
68	Known position error of pacer aircraft for condition (61) and (64), and possibly (66) or (67). (See Section 5.2.1).	$\left(\frac{p_m-p}{q_{cm}}\right)_{pacer}$	( )	(.xxxx)
69	(68) x (65).	$(p_m-p)_{pacer}$	( )	(x.xxx)"Hg
70*	Observer's meter on calibrator.	Meter reading	———	(xxx.)
71	Selected scale factor for meter at time of reading.	Scale factor	———	X(x.)
72	(15) x (70) x (71).	Δp_{uc}		(.xxx)"Hg
73	(72)-(18), Corrected pressure change for calibrator.	$(\Delta p_c)_{pacer}$		(.xxx)"Hg
74	(14)-(69)+(73), Change in true static pressure.	$p-(p)_o$		(.xxx)"Hg
Reading From Test Aircraft				
75	Pilot's airspeed indicator reading.	V_i	———	(xxx.)Knots
76	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.)Knots
77	(75)+(76), Corrected airspeed indicator reading.	V_m	-------	(xxx.)Knots
78	From (77) and Chart D-3.	q_{cm}		(xx.xxx)"Hg

*Values entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-3

C. Continued

Step	Description	Parameter	Value (Fill In)	Dimension
79	Angle of attack.	α	-------	(xx.x)Degrees
80	Gross weight of test aircraft.	W	-------	(xxx,x00.)Lbs
81*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
82	Selected scale factor for meter at time of reading.	Scale factor	____	X(x.)
83	(31) x (81) x (82).	Δp_{uc}		(.xxx)"Hg
84	(83)-(34), corrected pressure change for calibrator.	$(\Delta p_c)_{test}$		(.xxx)"Hg
85	(30)-(74)+(84).	$\Delta p=p_m-p$		(.xxx)"Hg
86	(85)/(78), Static pressure error of test aircraft.	$\Delta p/q_{cm}$	-------	(.xxxx)
87	(22)+(84), measured static pressure of test aircraft.	p_m		(xx.xxx)"Hg
88	(78)+(87), measured pitot pressure.	$p_{t'm}$		(xx.xxx)"Hg
89	(88)/(87).	$p_{t'm}/p_m$		(x.xxxx)
90	Mach number corresponding to $p_{t'm}/p_m$ from (89) and Table C-II or Reference 28.	M_m	-------	(.xxx)

*Value entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-3

D. Pitot Pressure Errors

NOTE: Pitot pressure errors for the test aircraft can also be investigated by adding a few data reduction steps to Form 8-3. Accuracy of pitot pressure calibration is dependent primarily on the accuracy of the altimeters and airspeed indicators in the pacer and test aircraft. Pitot pressure errors for the pacer's pitot tube installation must be known from previous calibration.

The following procedure is used:

Step	Description	Parameter	Value (Fill In)	Dimension
91	Known pitot pressure error of pacer aircraft for conditions (61), (64), and (66) or (67).	$\left(\frac{p'_{tm}-p'_t}{q_{cm}}\right)$ pacer	( )	(.xxxx)
92	(65) x (91).	$(p'_{tm}-p'_t)$ pacer		(x.xxx)"Hg
93	From (61) and Table C-I.	(p_m) pacer		(xx.xxx)"Hg
94	(65)-(93), measured pitot pressure of pacer.	(p'_{tm}) pacer		(xx.xxx)"Hg
95	(94)-(92), true pitot pressure.	p'_t		(x.xxx)"Hg
96	(88) - (95).	$(p'_{tm}-p'_t)$ test		(x.xxx)"Hg
97	(96)+(78), pitot pressure error of test aircraft.	$\left(\frac{p'_{tm}-p'_t}{q_{cm}}\right)$ test	-------	(.xxxx)

Form 8-3

E. Data Reduction [illegible] Recording Oscillograph

NOTE: If a recording oscillograph is used in the pacer aircraft to record the calibrator's signal, the following steps, marked by a prime ('), should be added to Form 8-3. Pressure differentials measured by the meter on the static port calibrator can also be recorded and used to check the oscillograph.

The special altimeter and airspeed indicator in the pacer could be replaced by transducers in the oscillograph. The pressure (q_{cm}) and (p_m) will then be obtained directly, and airspeed (V_m) and altitude (H_m), respectively, will be determined from these pressures using Chart D-3 for V_m and Table C-I for H_m.

Using the oscillograph, the observer in the pacer records the calibrator's pressure signal (and the altimeter and airspeed signals) at the data point by making a time mark on the oscillograph trace and recording the film footage number. He then records the zero and full scale calibrate signals from the calibrator.

Step	Description	Parameter	Value (Fill In)	Dimension
15'	Calibrated full-scale signal of calibrator (See Appendix A).	$(\Delta p)_{fs}$	( )	(.xxx)"Hg
16'*	Calibrator's signal trace minus calibrate zero trace (width between trace lines).	ΔX	____	(x.xx) In.
17'	Calibrate full-scale minus calibrate zero (width between trace lines).	ΔX_c	____	(x.xx) In.
18'	(15')x(16')/(17'), reference zero for calibrator	$(\Delta p)_o$		(.xxx)"Hg
41'*	Calibrator's signal trace minus calibrate zero trace (width between trace lines).	ΔX	____	(x.xx) In.
42'	Calibrate full-scale minus calibrate zero (width between trace lines).	ΔX_c	____	(x.xx) In.
43'	(15')x(41')/(42').	$(\Delta p)_f$		(.xxx)"Hg
70'*	Calibrator's signal trace minus calibrate zero trace (width between trace lines).	ΔX	____	(x.xx) In.
71'	Calibrate full-scale minus calibrate zero (width between trace lines).	ΔX_c	____	(x.xx) In.

Form 8-3

E. Continued

Step	Description	Parameters	Value (Fill In)	Dimensions
72'	(15') x (70')/(71').	$(\Delta p_c)_{uc}$		(.xxx)"Hg
73'	(72')-(18'), corrected pressure change for calibrator.	(Δp_c)pacer		(.xxx)"Hg

*Values entered must be corrected for any nonlinearity error, as explained in Appendix A.

Form 8-4

RADAR TRACKING CALIBRATION METHOD USING
STATIC PORT CALIBRATOR IN TEST
AIRCRAFT

(See Section 6)

Date:
Aircraft Type:
Aircraft Number:
Radar Test Site:
Prepared By:

A. Initial Values at Reference Airspeed (See Section 6.4.4)

Step	Description	Parameter	Value (Fill In)	Dimension
1		Date		
2	Time when pressure sample is sealed.	Time	____	
3	Clean, or with flaps, external stores, etc.	Aircraft Config.	____	
4*	Observer's altimeter reading.	$(H_i)_o$	____	(xx,xxx.)Ft
5	Instrument correction for altimeter.	ΔH_{ic}		(xxx.)Ft
6	(4)+(5), corrected altimeter reading.	$(H_m)_o$	-------	(xx,xxx.)Ft
7	Observer's airspeed indicator reading.	$(V_i)_o$	____	(xxx.)Knots
8	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.)Knots
9	(7)+(8), corrected airspeed indicator reading.	$(V_m)_o$		(xxx.)Knots
10	From (9) and Chart D-3.	$(q_{cm})_o$		(xx.xxx)"Hg
11**	Angle of attack.	α	____	(xx.x)Degrees
12**	Gross weight of aircraft.	W	____	(xxx,x00)Lbs
13	Known position error of aircraft for conditions (6) and (9), and possibly (11) or (12). (See Section 6.4.2).	$\left(\frac{P_m-P}{q_{cm}}\right)_o$	( )	(.xxxx)

* All altimeter readings to nearest 5 feet. Altimeters are at a setting of 29.92"Hg.
**Values may not be needed. Data reduction details to obtain parameters not included.

Form 8-4

A. Continued

Step	Description	Parameter	Value (Fill In)	Dimension
14	(13) x (10).	$(p_m-p)_o$		(x.xxx)"Hg
15	Calibrated pressure equivalent of units on Observer's meter. (See Appendix A).	Conversion constant	( )	(.xxxxx)"Hg/ unit on meter
16*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
17	Selected scale factor for meter at time of reading.	Scale factor	1.	X(x.)
18	(15)x(16)x(17), reference zero for calibrator.	$(\Delta p)_o$	-------	(.xxx)"Hg
19	From (6) and Table C-I.	$(p_m)_o$	-------	(xx.xxx)"Hg
20	(19)-(14), true static pressure at reference condition.	$(p)_o$	-------	(xx.xxx)"Hg
21**	(10)+(19), measured pitot pressure (assumed equal to true pitot pressure).	$(p'_{tm})_o$		(xx.xxx)"Hg
22	(21)/(20).	$(p'_{tm}/p)_o$		(x.xxxx)
23	True Mach number corresponding to $(p'_{tm}/p)_o$ from (22) and Table C-II.	$(M)_o$		(x.xxx)
24	Total temperature reading.	$(T_{tm})_o$	____	(xxx.x)°R
25	Recovery factor of Total Temperature Sensor.	r	( )	(.xxx)
26	$(T_{tm})_o/\left[1+0.2r(M)_o^2\right]$, outside air static temperature. Determined from (23), (24), and (25).	$(T)_o$	-------	(xxx.x)°R
27	Slant range of radar.	$(Range)_o$	____	(xxx,xxx.)Ft
28	Elevation angle of radar.	$(El)_o$	____	(xx.xxxx)Deg.
29	Azimuth angle of radar.	$(Az)_o$	____	(xx.xxxx)Deg.
30	Aircraft height when pressure sample is sealed. From (27) and (28).	$(h)_o$	____	(xx,xxx.)Ft

*Values entered must be corrected for any nonlinearity scale error, as described in Appendix A.

**Measured pitot pressure should be corrected for any known errors.

Form 8-4

B. Final Check Values at Reference Airspeed (See Section 6.4.4)

Step	Description	Parameter	Value (Fill In)	Dimension
31	Time of data recording.	Time	____	
32	Observer's airspeed indicator.	$(V_i)_f$	____	(xxx.)Knots
33	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.)Knots
34	(32)+(33), corrected airspeed indicator reading.	$(V_m)_f$		(xxx.)Knots
35*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
36	Selected scale factor for meter at time of reading.	Scale factor	__1.__	X(x.)
37	(15)x(35)x(36).	$(\Delta p)_f$		(.xxx)"Hg
38	(37)-(18).	$(\Delta p)_f-(\Delta p)_o$		(.xxx)"Hg
39	Angle of attack.	α	____	(xx.x)Degrees
40	Gross weight of pacer aircraft.	W	____	(xxx,x00)Lbs
41	From (34) and Chart D-3.	$(q_{cm})_f$		(xx.xxx)"Hg
42	(13)x(41).	$(p_m-p)_f$		(x.xxx)"Hg
43	(19)+(38),measured static pressure.	$(p_m)_f$		(xx.xxx)"Hg
44	(43)-(42), true static pressure.	$(p)_f$		(xx.xxx)"Hg
45	(41)+(43), measured pitot pressure (assumed equal to true pitot pressure).	$(p_{t'm})_f$		(xx.xxx)"Hg
46	(45)/(44).	$(p_{t'm}/p)_f$		(x.xxxx)
47	True Mach number corresponding to $(p_{t'm}/p)_f$ from (46) and Table C-I.	$(M)_f$		(x.xxx)
48	Total temperature reading.	$(T_{tm})_f$	____	(xxx.x)°R
49	Recovery factor of Total Temperature Sensor.	r	( )	(.xxx)
50	$(T_{tm})_f/\left[1+0.2r(M)_f^2\right]$, outside air static temperature; determined from (47), (48), and (49).	$(T)_f$		(xxx.x)°R
51	Slant range of radar.	$(\text{Range})_f$	____	(xxx,xxx.)Ft

*Values entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-4

B. Continued

Step	Description	Parameter	Value (Fill In)	Dimensions
52	Elevation angle of radar.	$(El)_f$	____	(xx.xxxx)Deg.
53	Azimuth angle of radar.	$(Az)_f$	____	(xx.xxxx)Deg.
54	Aircraft height at reference airspeed recheck point, from (51) and (52).	$(h)_f$	____	(xx,xxx.) Ft
55	$[(54)-(30)]/(26)$.	$[(h)_f-(h)_o]/(T)_o$		(x.xxx)Ft/°R
56	From (55) and Chart D-2.	$[(p)_f-(p)_o]/(p)_o$		(.xxxxx)
57	(56) x (20), calculated change in true static pressure.	$[(p)_f-(p)_o]$ Calc.		(.xxx)"Hg
58	(44)-(20), measured change in true static pressure.	$[(p)_f-(p)_o]$ Meas.		(.xxx)"Hg
59	(57)-(58), if greater than ± 0.005 inches Hg, suspect instability of trapped pressure sample (19), or a change of reference calibration (13) with change in α or W.	Discrepancy in true static pressure		(.xxx)"Hg

Form 8-4

C. Data Reduction For Each Test Point (See Section 6.4.4)

Step	Description	Parameter	Value (Fill In)	Dimensions
60	Time of data recording.	Time	____	
61	Clean, or with flaps, external stores, etc.	Aircraft Config.	____	
62	Observer's airspeed indicator reading.	V_i	____	(xxx.)Knots
63	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.)Knots
64	(62)+(63), Corrected airspeed indicator reading.	V_m		(xxx.)Knots
65	From (64) and Chart D-3.	q_{cm}		(xx.xxx)"Hg
66	Angle of attack.	α	____	(xx.x)Degrees
67	Gross weight of aircraft.	W	____	(xxx,x00)Lbs
68*	Observer's meter on calibrator.	Meter reading	____	(xxx.)
69	Selected scale factor for meter at time of reading.	Scale factor	____	X(x.)
70	(15)x(68)x(69).	$(\Delta p)_{uc}$		(.xxx)"Hg
71	(70)-(18), corrected pressure change for calibrator.	$(\Delta p)_c$		(.xxx)"Hg
72	(19)+(71), measured static pressure.	p_m		(.xxx)"Hg
73	Slant range of radar.	(Range)	____	(xxx,xxx.)Ft
74	Elevation angle of radar.	El	____	(xx.xxxx)Deg.
75	Azimuth angle of radar.	Az	____	(xx.xxxx)Deg.
76	Aircraft height at test point. From (73) and (74).	h	____	(xx,xxx.)Ft
77	$[(76)-(30)]/(26)$.	$[h-(h)_c]/(T)_o$		(x.xxx)Ft/°R
78	From (77) and Chart D-2, (use standard temperature lapse rate for altitude H_m).	$[p-(p)_o]/(p)_o$		(.xxxxx)
79	(78) x (20).	$p-(p)_o$		(x.xxx)"Hg
80	(79) + (20), true static pressure.	p		(xx.xxx)"Hg

*Values entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

Form 8-4

C. Continued

Step	Description	Parameter	Value (Fill In)	Dimensions
81	(65)+(72), measured pitot pressure (assumed equal to true pitot pressure)	$P_{t'm}$		(xx.xxx)"Hg
82	(81)/(80).	$P_{t'm}/p$		(x.xxxx)
83	True Mach number, corresponding to $P_{t'm}/p$ from (82) and Table C-II.	M		(x.xxx)
84	Total temperature reading.	T_{tm}	____	(xxx.x)°R
85	Recovery factor of total temperature sensor.	r	( )	(.xxx)
86	$T_{tm}/[1+0.2r(M)^2]$, outside air static temperature, determined from (83), (84), and (85).	T		(xxx.x)°R
87*	[(86)-(26)]/[(76)-(30)], temperature lapse rate from reference to test condition.	L		(.xxxx)°R/Ft
88	(72)-(80).	$\Delta p = p_m - p$		(.xxx)"Hg
89	(88)/(65), static pressure error of test aircraft.	$\Delta p/q_{cm}$	-------	(.xxxx)
90	(81)/(72).	$P_{t'm}/P_m$		(x.xxxx)
91	Mach number corresponding to $P_{t'm}/P_m$ from (90) and Table C-II.	M_m	-------	(x.xxx)

*If lapse rate is significantly different from the value used in (78), and if $[h-(h)_o]/(T)_o$ in (77) is greater than 1.0 ft/°R, use exact equation on Page D-2 to calculate $[p-(p)_o]/(p)_o$. Using this pressure ratio, then recalculate (79), (80), (88), and (89) for correct value of $\Delta p/q_{cm}$.

Form 8-4

D. Data Reduction of Recording Oscillograph

NOTE: If a recording oscillograph is used in the test aircraft to record the calibrator's signal, the following steps, marked by a prime (') should be added to Form 8-4. Pressure differentials measured by the meter on the static port calibrator can also be recorded and used to check the oscillograph.

The special altimeter and airspeed indicator in the test aircraft could be replaced by transducers in the oscillograph. The pressures (q_{cm}) and (p_m) will then be obtained directly, and airspeed (V_m) and altitude (H_m), respectively, will be determined from these pressures using Chart D-3 for V_m and Table C-II for H_m.

Using the oscillograph, the flight observer records the calibrator's pressure signal (and the altimeter and airspeed pressure signals) at the data point by marking a time mark on the oscillograph trace and recording the film footage number. He then records the zero and full scale calibrate signals from the calibrator.

Step	Description	Parameter	Value (Fill In)	Dimensions
15'	Calibrated full-scale signal of calibrator (See Appendix A).	$(\Delta p)_{fs}$	( )	(.xxx)"Hg
16'*	Calibrator's signal trace minus calibrate zero trace (width between trace lines).	ΔX	____	(x.xx) In.
17'	Calibrate full-scale minus calibrate zero (width between trace lines).	ΔX_c	____	(x.xx) In.
18'	(15')x(16')/(17'), reference zero for calibrator.	$(\Delta p)_o$		(.xxx)"Hg
35'*	Calibrator's signal trace minus calibrate zero trace (width between trace lines).	ΔX	____	(x.xx) In.
36'	Calibrate full-scale minus calibrate zero (width between trace lines).	ΔX_c	____	(x.xx) In.
37'	(15') x (35')/(36').	$(\Delta p)_f$		(.xxx)"Hg
68'*	Calibrator's signal trace minus calibrate zero trace (width between trace lines).	ΔX	____	(x.xx) In.

*Value entered must be corrected for any nonlinearity error as described in Appendix A.

Form 8-4

D. Continued

Step	Description	Parameter	Value (Fill In)	Dimensions
69'	Calibrate full-scale minus calibrate zero (width between trace lines).	ΔX_c	______	(x.xx) In.
70'	(15') x (68')/(69').	$(\Delta p)_{uc}$		(.xxx)"Hg
71'	(70') - (18'), corrected pressure change for calibrator.	$(\Delta p)_c$		(.xxx)"Hg

Form 8-5

TRAILING CONE FLIGHT CALIBRATION METHOD

(See Section 7)

Date:
Aircraft Type:
Aircraft Number:
Prepared By:

A. Data Reduction For Each Test Point (See Section 7.3.4)

Step	Description	Parameter	Value (Fill In)	Dimensions
1		Date		
2	Time of data recording.	Time	____	
3	Clean, or with flaps, external stores, etc.	Aircraft Config.	____	
4*	Observer's altimeter reading.	H_i	____	(xx,xxx.)Ft
5	Instrument correction for altimeter.	ΔH_{ic}		(xxx.) Ft
6	(4)+(5), corrected altimeter reading.	H_m	-------	(xx,xxx.)Ft
7	Observer's airspeed indicator reading.	V_i	____	(xxx.) Knots
8	Instrument correction for airspeed indicator.	ΔV_{ic}		(xx.) Knots
9	(7)+(8), corrected airspeed indicator reading.	V_m	-------	(xxx.)Knots
10	From (9) and Chart D-3.	q_{cm}		(xx.xxx)"Hg
11**	Angle of attack.	α	____	(xx.x)Degrees
12**	Gross weight of aircraft.	W	____	(xxx,x00)Lbs
13***	Calibrated pressure equivalent of units on Observer's meter. (See Appendix A).	Conversion Constant	( )	(.xxxxx)"Hg/ unit on meter

* Altimeter reading to nearest 5 feet. Altimeter is at a setting of 29.92"Hg.

**Values may not be needed. Data reduction details to obtain parameters not included.

***Omit Step (13) if conversion chart is used to obtain (p_m - p), Step (15), directly from Meter Reading, Step (14)

Form 8-5

A. Continued

Step	Description	Parameter	Value (Fill In)	Dimensions
14*	Observer's meter on calibrator.	Meter reading	———	(xxx.)
15	(13)x(14), measured static pressure minus cone static pressure.	$p_m - p_c$		(.xxx)"Hg
16	Position Error of Trailing Cone (Determined from previous calibration).	$(p_c-p)/q_{cm}$	( )	(.xxxx)
17	(10)x(16), cone's static pressure error.	p_c-p		(.xxx)"Hg
18	(15)+(17), measured static pressure error.	p_m-p		(.xxx)"Hg
19	(18)/(10), static pressure error of test aircraft.	$\Delta p/q_{cr}$	-------	(.xxxx)
20	From (6) and Table C-I.	p_m		(xx.xxx)"Hg
21	1. + (10)/(20).	$p_{t'm}/p_m$		(x.xxxx)
22	Mach number corresponding to $p_{t'm}/p_m$ from (21) and Table C-II.	M_m	-------	(x.xxx)

*Value entered must be corrected for any nonlinearity scale error, as explained in Appendix A.

B. Data Reduction of Recording Oscillograph

NOTE: If a recording oscillograph is used in the test aircraft to record the pressure gage signal, the following four steps should be added to Form 8-5. Pressure differentials measured by the meter on th special differential pressure gage can also be recorded and used to check the oscillograph.

The special altimeter and airspeed indicator in the test aircraft could be replaced by transducers in the oscillograph. The pressures (q_{cm}) and (p_m) will then be obtained directly, and airspeed (V_m) and altitude (H_m), respectively, will be determined from these pressures using the reverse of Steps (10) and (17).

Using the oscillograph, the flight observer records the differential pressure signal (and the altimeter and airspeed pressure signals) at the data point by making a time mark on the oscillograph trace and recording the film footage number. He then records the zero and full scale calibrate signals from the pressure gage.

Step	Description	Parameter	Value (Fill in)	Dimensions
20	Pressure gage full-scale signal of calibrator (See Appendix A).	$(\Delta p)_{fs}$	( )	(.xxx)"Hg
21*	Pressure gage signal trace minus calibrate zero trace (width between trace lines).	ΔX	____	(x.xx) In.
22	Calibrate full-scale minus calibrate zero (width between trace lines).	ΔX_c	____	(x.xx) In.
23	(20)x(21)/(22), static pressure error recorded by oscillograph.	$(p_m-p)_{osc}$		(.xxx)"Hg
24	(23)/(10), static pressure error of test aircraft, from oscillograph recording.	$(\Delta p/q_{cm})_{osc.}$	-------	(.xxxx)

*Value entered must be corrected for any nonlinearity error, as explained in Appendix A.

FIGURE 8.1a

(Form 7-1) Page 1 of 2

TEST SEQUENCE CARD FOR PILOT OF TEST AIRCRAFT

(Fill In Before Tests Begin)

Date: 25 JUNE, 1965
Aircraft Type: REC 525 Z
Aircraft Number: Y 2018 Z
Pilot: John D. Doe

Test Point	Aircraft Config.	Test Altitude (xx,xxx.)Ft	Test Airspeed (xxx.)Knts	Remarks
1	CLEAN	10,000	200	
2			260	
3			320	
4			360	
5			440	
6			440	
7			380	
8			320	
9			260	
10			200	
11			200	
12			260	
13			320	
14			380	
15			440	
16	PARTIAL FLAPS	10,000	160	20° FLAPS
17			190	
18			220	
19			220	
20			190	
21			160	
22			160	
23			190	
24			220	

FIGURE 8.1b

(Form 7-1) Page 2 of 2

<u>TIME SEQUENCE CARD FOR PILOT OF TEST AIRCRAFT</u>

(Fill In Before Tests Begin)

Date: 25 June, 1965
Aircraft Type: REC 525 Z
Aircraft Number: Y 2018 Z
Pilot: John D. Doe

Test Point	Aircraft Config.	Test Altitude (xx,xxx.)Ft	Test Airspeed (xxx.)Knots	Remarks
25	PARTIAL FLAPS + GEAR EXTENDED	10,000	140	20° FLAPS
26			170	
27			200	
28			200	
29			170	
30			140	
31			140	
32			170	
33			200	
34	FULL FLAPS + GEAR EXTENDED		120	40° FLAPS
35			150	
36			180	
37			180	
38			150	
39			120	
40			120	
41			150	
42			180	

FIGURE 8.2a

(Form 7-2) Page 1 of 2

DATA CARD FOR FLIGHT OBSERVER

Date: 25 June, 1965
Aircraft Type: REC 525 Z
Aircraft Number: Y 2018 Z
Data Taken By: John J. Jones

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)					
Test Point	Aircraft Config.	Test Altitude (xx,xxx.) Feet	Test Airspeed (xxx.) Knots	Meter Reading (xxx.)	Altimeter Reading (xx,xxx.) Feet	Airspeed Reading (xxx.) Knots	Gross Weight (xxx,x00) Lbs	Time	Remarks
1	CLEAN	10,000	200	-21	9,945	196	205,300	5:23AM	
2			260	-37	9,935	263		:25	
3			320	-40	9,965	321		:28	
4			380	-56	9,950	381		:30	
5			440	-22	9,945	443		:33	
6			440	-10	9,935	447	204,200	5:36	
7			380	-66	9,950	382		:39	
8			320	-57	9,945	322		:41	
9			260	-39	9,920	263		:44	
10			200	-21	9,950	200		:47	
11			200	-25	9,970	199	202,900	5:52	
12			260	-33	9,960	261		:59	
13			320	-54	9,940	318		6:02	
14			380	-71	9,935	382		:06	
15			440	-23	9,945	445		:09	
16	PARTIAL FLAPS	10,000	160	-22	9,960	157	201,300	6:18	
17			190	-31	9,945	192		:20	
18			220	-42	9,930	218		:23	
19			220	-45	9,945	218	200,500	6:25	
20			190	-32	9,955	191		:29	
21			160	-21	9,955	152		:32	
22			160	-22	9,940	154	199,900	6:34	
23			190	-40	9,925	189		:36	
24			220	-45	9,950	221		:39	

FIGURE 8.2b

(Form 7-2) Page 2 of 2

<u>DATA CARD FOR FLIGHT OBSERVER</u>

Date: 25, June, 1965
Aircraft Type: REC 525 Z
Aircraft Number: Y2018 Z
Data Taken By: John J. Jones

(FILL IN BEFORE TESTS BEGIN)				(RECORD AT EACH TEST POINT)					
Test Point	Aircraft Config.	Test Altitude	Test Airspeed	Meter Reading	Altimeter Reading	Airspeed Reading	Gross Weight	Time	Remarks
		(xx,xxx.) Feet	(xxx.) Knots	(xxx.)	(xx,xxx.) Feet	(xxx.) Knots	(xxx,x00) Lbs		
25	PARTIAL FLAPS + GEAR EXTENDED	10,000	140	-9	9,940	139	199,300	6:44	
26			170	-12	9,960	164		:46	
27			200	-20	9,930	199		:49	
28			200	-20	9,930	196	189,900	6:51	
29			170	-14	9,945	169		:53	
30			140	-10	9,945	139		:55	
31			140	-10	9,945	139	189,400	6:57	
32			170	-13	9,950	168		7.00	
33			200	-19	9,940	198		:02	
34	FULL FLAPS + GEAR EXTENDED		120	-6	9,935	117	188,800	7:05	
35			150	-11	9,945	148		:07	
36			180	-16	9,925	178		:10	
37			180	-10	9,940	175	188,400	7:12	
38			150	-12	9,965	151		:15	
39			120	-7	9,945	119		:18	
40			120	-7	9,950	115	188,000	7:20	
41			150	-11	9,960	148		:22	
42			180	-16	9,930	181		:25	

FIGURE 8 3

(Form 8-5)

TRAILING CONE FLIGHT CALIBRATION METHOD

Date 25 June, 1965
Aircraft Type REC 825 Z
Aircraft Serial Number Y 2015 Z
Prepared By John J Jones

Test Point	1 Date	2 Time	3 Aircraft Configuration	4 H_i Ft xx,xxx	5 ΔH_{ic} Ft xxx	6 (4) + (5) H_m Ft xx,xxx	7 V_i Knots xxx	8 ΔV_{ic} Knots x	9 (7) + (8) V_m Knots xxx	10 Chart D-3 q_{cm} " Hg xx.xxx	11 α Deg. xx.x	12 nW Lbs. xxx,x00	13 Conv Const " Hg / unit .xxxxx	14 Cor. Meter Reading xxx.	15 (13) x (14) $p_m - p_c$ " Hg .xxx	16 $\frac{(p_c - p)}{q_{cm}}$ x.xxx	17 (10) x (16) $p_c - p$ " Hg .xxx	18 (15) x (17) $p_m - p$ " Hg .xxx	19 $\frac{(18)}{(10)}$ $\frac{\Delta p}{q_{cm}}$ .xxxx	20 Table C-I pm " Hg xx.xxx	21 $1 + \frac{(10)}{(20)}$ $\frac{p_{t'm}}{pm}$ x.xxxx	22 Table C-II M_m x.xxx
1	6/25/65	[illegible]	CLEAN	9,945	+55	10,000	196	+2	198	1.919	11.8	205,300	.00100	-21	-.021	+.0020	+.004	-.017	-.0069	20.511	1.0935	.359
2		25		9,955		9,990	263	-1	262	3.411	8.6			-37	-.037		+.007	[illegible]	-.0080	20.565	1.1160	.494
3		[illegible]		9,965		10,020	321	-1	320	5.195	5.8			-40	-.040		+.010	-.057	-.0096	20.561	1.2527	.711
4		30		9,950		10,005	321	-2	319	7.459	5.0			-56	-.056		+.015	-.041	-.0056	20.573	1.3626	[illegible]
5		33		9,945		[illegible]	443	2	441	10.390	.2			-22	-.022		+.021	-.001	-.0001	20.577	[illegible]	.787
6		5 35		9,935		9,990	441	-2	445	10.005	.1	204,200		-10	-.010		+.021	+.011	+.0010	20.595	[illegible]	.194
7		39		9,950		[illegible]	382	2	380	[illegible]	2.9			[illegible]	-.026		+.015	-.051	-.0028	20.513	[illegible]	.482
8		41		9,945		[illegible]	322	1	321	[illegible]	5.1			-57	-.051		+.010	-.041	-.0090	[illegible]	1.2042	.518
9		44		9,930		9,975	[illegible]	-1	262	[illegible]	3.7			-39	-.039		+.007	-.052	-.0094	20.597	1.1659	.473
10		47		9,950		[illegible]	200	+2	202	1.999	11.6			21	-.021		+.004	-.017	-.0085	20.573	1.0972	[illegible]
11		5:52		9,910		10,045	199	+2	201	1.979	11.7	202,900		-25	-.025		+.004	-.021	[illegible]	20.557	1.0963	.305
12		59		9,960		10,015	261	-1	260	3.365	8.9			33	-.033		+.007	-.026	-.0077	20.565	1.1635	.470
13		6 02		9,940		9,995	318	-1	317	5.093	6.0			[illegible]	-.054		+.010	-.044	-.0086	20.561	1.2470	.571
14		06		9,935		9,990	382	-2	380	7.501	2.9			-71	-.071		+.015	-.066	-.0015	20.590	1.3644	.651
15		09		9,945		10,000	445	-2	443	10.498	.1			-23	-.023		+.021	-.002	-.0002	20.577	1.5100	.790
16		6 18	PARTIAL FLAPS	9,960		10,015	157	+3	160	1.243	10.3	201,300		-22	-.022	+.0040	+.005	-.017	-.0137	20.565	1.0604	.291
17		20		9,946		10,000	192	0	192	1.802	9.8			-31	-.031		+.007	-.024	-.0133	20.577	1.0876	.349
18		23		9,930		9,985	218	+2	220	2.382	7.5			-42	-.042		+.010	-.032	-.0134	20.589	1.1157	.399
19		6 25		9,945		10,000	218	+2	220	2.382	7.6	200,500		-45	-.045		+.010	-.035	-.0147	20.511	1.1158	.399
20		29		9,955		10.010	191	0	191	1.783	9.9			-32	-.032		+.007	-.025	-.0140	20.569	[illegible]	.447
21		32		9,955		10,010	152	+3	155	1.166	10.5			-21	-.021		+.008	-.016	-.0131	20.569	[illegible]	.282
22		[illegible]		9,940		9,995	[illegible]	[illegible]	157	1.197	10.3	199,500		-22	-.022		+.005	-.011	-.0142	20.581	1.0582	.285
23		36		9,925		9,980	189	0	189	1.745	10.1			-40	-.040		+.007	-.033	-.0189	20.593	1.0847	.343
24		39		9,945		10,005	221	+2	223	2.449	7.4			-45	-.045		+.010	-.035	-.0143	20.513	1.1190	.404
25		6 44	FLAPS GEAR	9,940		9,995	139	+2	141	0.963	9.5	199,300		-9	-.009	+.0060	+.006	-.003	-.0031	20.561	1.0468	.256
26		46		9,960		10,015	164	+1	165	1.324	8.2			-12	-.012		+.008	-.004	-.0030	20.566	1.0644	.300
27		[illegible]		[illegible]		9,965	199	+2	201	1.979	6.4			-20	-.020		+.012	-.008	-.0040	20.589	1.0961	.364
28		6 51	PARTIAL +	9,930		9,980	196	+2	198	1.919	6.3	189,900		-20	-.020		+.012	-.008	-.0042	20.589	1.0932	.359
29		55		9,945		10,000	169	+1	170	1.406	7.9			-14	-.014		+.008	-.006	-.0043	20.577	1.0683	.309
30		58		9,945		10,000	139	+2	141	0.963	9.4			-10	-.010		+.006	-.004	-.0042	20.577	1.0468	.256
31		6 57		9,946		10,000	139	+2	141	0.963	9.4	189,400		-10	-.010		+.006	-.004	-.0042	20.577	1.0468	.256
32		7 00		9,950		10,005	168	+1	169	1.390	8.0			-13	-.013		+.008	-.005	-.0036	20.573	1.0676	.307
33		02		9,940		9,995	198	-2	200	1.959	6.5			-19	-.019		+.012	-.007	-.0036	20.581	1.0952	.363
34		7 05	FLAPS GEAR	9,935		9,990	117	+3	120	0.695	9.3	188,800		-6	-.006		+.004	-.008	-.0029	20.565	1.0338	.219
35		07		9,945		10,000	148	+2	150	1.090	7.8			-11	-.011		+.007	-.004	-.0037	20.577	1.0530	.273
36		10		9,925		9,980	178	0	178	1.544	6.5			-16	-.016		+.009	-.007	-.0046	20.555	1.0750	.323
37		7 12	FULL +	9,940		9,995	175	0	175	1.492	6.5	188,400		-10	-.010		+.007	-.001	-.0007	20.581	1.0725	.318
38		15		9,965		10,020	151	+2	153	1.136	7.7			-12	-.012		+.007	-.005	-.0044	20.561	1.0553	.278
39		18		9,945		10,000	119	+3	122	0.719	9.2			-7	-.007		+.009	-.003	-.0046	20.577	1.0549	.222
40		7 20		9,950		10,005	115	+3	118	0.672	9.3	188,000		-7	-.007		+.004	-.003	-.0046	20.573	1.0327	.215
41		22		9,960		10,015	148	+2	150	1.090	7.8			-11	-.011		+.007	-.004	-.0037	20.565	1.0530	.273
42		28		9,930		9,985	181	0	181	1.598	6.3			-16	-.016		+.010	-.006	-.0035	20.589	1.0776	.329

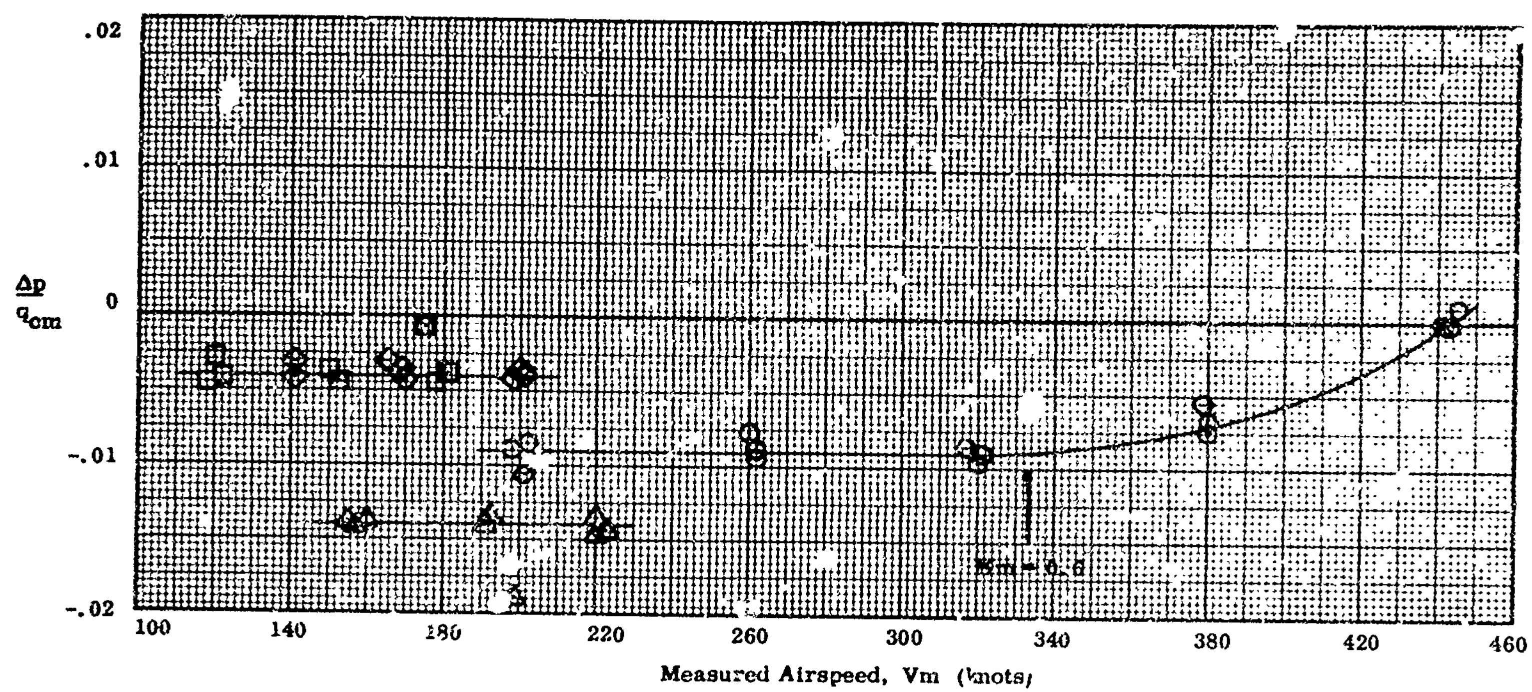

Figure 8.4

Static Pressure Position Error as a Function of Measured Airspeed
REC 525Z Aircraft, Number Y2018X, Trailing Cone Calibration, 25 June 1965

H = 10,000 feet, Gross Weight ≅ 200,000 lbs.

O = Clean Configuration
Δ = Partial Flaps
◇ = Partial Flaps and Gear
□ = Full Flaps and Gear

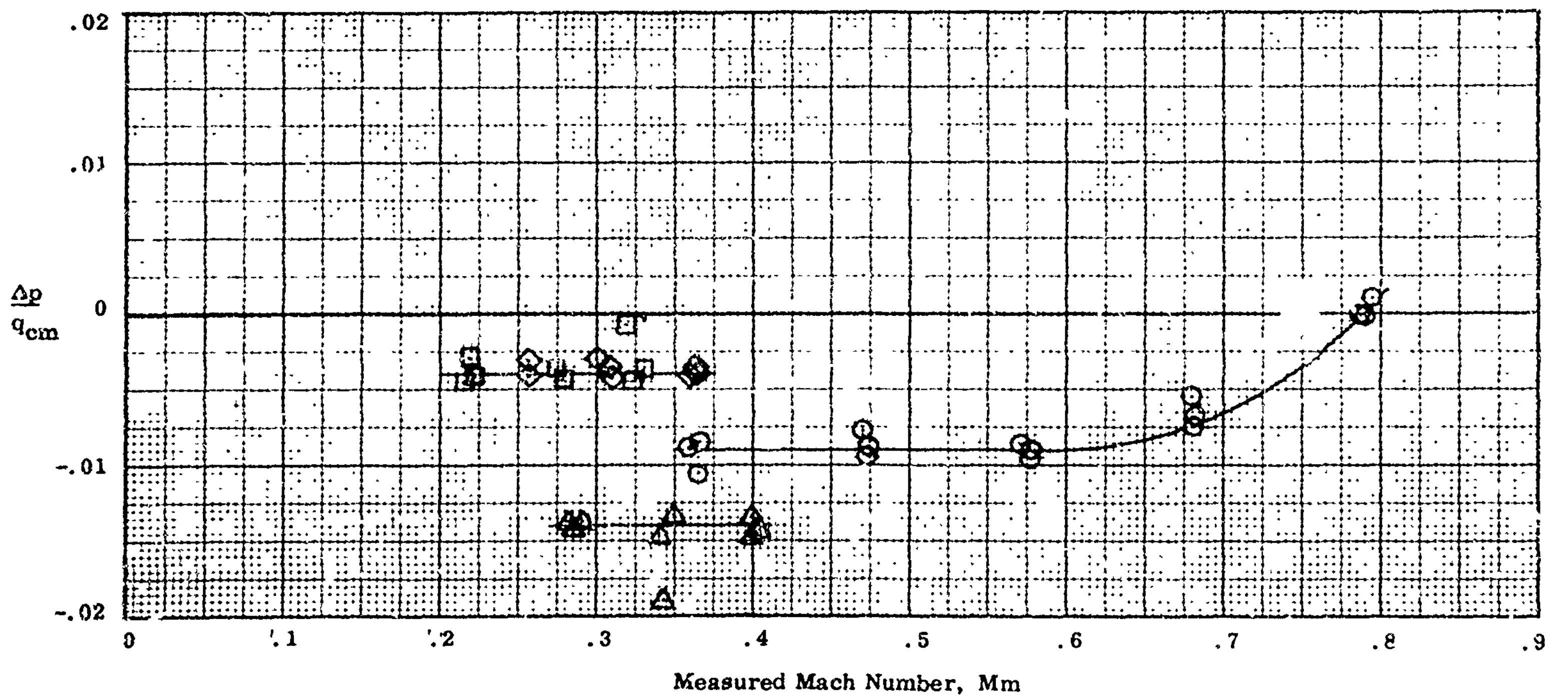

Figure 8.5

Static Pressure Position Error as a Function of Measured Mach Number
REC 525Z Aircraft, Number Y2018X Trailing Cone Calibration, 25 June 1965

H = 10,000 feet, Gross Weight ≅ 200,000 lbs.

O = Clean Configuration
Δ = Partial Flaps
◇ = Partial Flaps and Gear
□ = Full Flaps and Gear

FIGURE 8 6

DETERMINATION OF ALTITUDE CORRECTION FROM STATIC PRESSURE POSITION ERROR, FIGURE 8 4

REC 525Z Aircraft, Serial Number Y2018Z
TRAILING CONE CALIBRATION, 25 June 1965

1	2	3	4	5	6	7	8	9	10	11
Aircraft Config.	True Pressure Altitude	From (2) and Table C-111	Measured Airspeed	From (4) and Chart D-3	From (4) and Figure 8.4	(5) x (6)	From (3), (7), and Chart D-1	From (6) and Chart D-1	(8) + (9)	(2) - (8)
	H ft	σ	V_m Knots	q_{cm}	$\Delta p / q_{cm}$	Δp " Hg	$(\Delta H_c)^*$ ft	$\Delta H_c - (\Delta H_c)^*$ ft	ΔH_c ft	H_m ft
	xx, xxx	xxxxx	xxx.	xx, xxx	.xxxx	xxxx	xxx	xx	xxx.	xx, xxx
CLEAN	0	1 00000	200	1 959	- 0090	- 0176	-16	0		15
			220	2 382		- 0214	-20			20
			240	2 849		- 0256	-24			25
			260	3 363		- 0303	-28			30
			280	3 924		- 0353	-33			35
			300	4 554		- 0403	-38			40
			320	5 195		- 0448	43			45
			340	5 909		- 0532	-47			50
			360	6 617		- 0601	-50			55
			380	7 [illegible]		- 0[illegible]	62			60
			400	8 385		- 0755	-70			70
	10,000	73848	200	1 959		- 0176	-22			10,020
			220	2 382		- 0214	27			10,030
			240	2 849		- 0256	-32			10 030
			260	3 363		- 0303	-38			10,040
			280	3 [illegible]		- 0353	-44			10,045
			300			- 0408	-51			10,050
			320			0468	-59			10,060
			340			- 0532	-61			10,065
	20,000	53281	200			- 0176	-31			20,030
			220	2 3[illegible]		- 0214	-37			20,035
			240	2 849		0256	-44			20,04[illegible]
			260	3 363		- 0303	-53			20,0[illegible]
	30,000	37413	200	1 959		- 0176	-44			30,045
			220	2 382	(NO ANGLE OF ATTACK INFLUENCE)	- 0214	-53			30,05[illegible]
PARTIAL FLAPS	0	1 00000	160	1 245	- 0140	- 0174	-16		SAME AS $(\Delta H_c)^*$	15
			180	1 580		- 0221	-20			20
			200	1 959		- 0274	-25			25
			220	2 382		- 0335	-31			30
	5,000	86167	160	1 243		- 0174	-19			5,020
			180	1 580		- 0221	-24			5 025
			200	1 959		0274	-29			5,030
			220	2 382		- 0335	-36			5 035
	10,000	73848	160	1 245		- 0174	-22			10,020
			180	1 580		- 0221	-28			10,030
			200	1 959		- 0274	-34			10,035
			220	2 382		- 0335	-42			10,040
	15,000	62923	160	1 245		- 0174	-21			15,025
			180	1 580		- 0221	-32			15,030
			200	1 959		- 0274	-40			15,040
			220	2 382	(NO ANGLE OF ATTACK INFLUENCE)	- 0333	-49			15,050
+ GEAR	0	1 00000	140	0 995	- 0040	- 0040	-4			5
			160	1 245		- 0050	-5			5
			180	1 580		0065	-6			5
			200	1 959		- 0078	-7			5
PARTIAL FLAPS	5 000	86167	140	0 995		- 0040	-4			5,005
			160	1 243		- 0050	-5			5,005
			180	1 580		- 0065	-7			5 005
			200	1 959		- 0078	-8			5,010
	10,000	73848	140	0 995		- 0040	-5			10,005
			160	1 245		- 0050	-6			10,005
			180	1 580		- 0065	-8			10 010
			200	1 959	(NO ANGLE OF ATTACK INFLUENCE)	- 0078	-10			10,010
+ GEAR	0	1 00000	120	0 695	- 0040	- 0028	-3			5
			140	0 995		- 0040	-4			5
			160	1 245		- 0050	-5			5
			180	1 580		- 0065	-6			5
FULL FLAPS	5,000	86167	120	0 695		- 0028	-3			5,005
			140	0 995		- 0040	-4			5,005
			160	1 245		- 0050	-5			5 005
			180	1 580		- 0065	-7			5,005
	10,000	73848	120	0 695		- 0028	-4			10,005
			140	0 995		- 0040	-5			10,005
			160	1 245		- 0050	-6			10,005
			180	1.580	(NO ANGLE OF ATTACK INFLUENCE)	- 0063	-8			10,010

FIGURE 8 7

DETERMINATION OF ALTITUDE CORRECTION FROM STATIC PRESSURE POSITION ERROR, FIGURE 8 5

REC 525Z Aircraft Serial Number Y2018Z
TRAILING CONE CALIBRATION, 25 June 1965

1	2	3	4	5	6	7	8	9	10	11
True Pressure Altitude	Measured Mach Number	From (2) and Table C-II	(3) - 1 0	From (2) and Figure 8 4	(4) x (5)	1. - (6)	(6) x p / (7)	From (8) σ and Chart D-I	From (9) and Chart D-1	(1) - (10)
H ft.	M_m	$P_t'm / P_m$	q_{cm} / P_m	$\Delta p / q_{cm}$	$\Delta p / P_m$	p / p_m	Δp " Hg	$(\Delta H_c)^*$ ft.	$(\Delta H_c)-(\Delta H_c)^*$ ft.	H_m ft.
xx, xxx	x xxx	x. xxx	x. xxxx	xxxx	xxxxx	x. xxxxx	xxxx	xxx	xx	xx, xxx
	P - 29 9213" Hg		σ = 1.0000	(p and σ from (1) and table C III)						
0	300	1 06443	06443	- 0090	- 00068	1 00068	- 0203	- 9	0	20
	400	1 11663	1166	- 0090	00105	1 00105	- 0314	- 29		30
	500	1 1862	1862	- 0090	- 00168	1 00168	- 0502	-46		45
	600	1 2755	2755	- 0090	00248	1 00248	- 0140	- 68		70
	700	1 3871	3871	- 0065	- 00252	1 00252	- 0752	- 70		70
	750	1 4523	4523	- 0035	- 00158	1 00158	- 0472	- 44		45
	800	1 5243	5243	+ 0014	+ 00073	1 00073	+ 0219	+ 20		- 20
	P = 20 5769 " Hg		σ = 73848							
10.000	400	1 1166	1166	- 0090	- 00105	1 00105	- 0210	- 7	ΔHc = (ΔHc)o	10 025
	500	1 1862	1862	- 0090	- 00168	1 00168	- 0345	- 43		10 046
	600	1 2755	2755	- 0090	- 00248	1 00248	- 0509	- 64		10 065
	700	1 3871	3871	- 0065	- 00252	1 00252	-.0517	65		10 065
	750	1 4523	4523	- 0035	- 00158	1 00158	- 0325	41		10.040
	800	1 5243	5243	+ 0014	+ 00073	1 00073	+ 0150	+ 19		9,980
	P = 13 7501 " Hg		σ = .53281							
20 000	500	1 1862	1862	- 0090	-.00168	1 00168	- 0231	-40		20 040
	600	1 2755	2755	- 0090	- 00248	1 00248	- 0340	- 59		20,060
	700	1 3871	3871	- 0065	- 00252	1 00252	- 0346	- 60		20,060
	750	1 4523	4523	- 0035	-.00158	1 00158	0217	- 38		20,040
	800	1 5243	5243	+ 0014	+ 00073	1 00073	+ 0100	+ 17		19,985
	P = 8 88541 " Hg		σ = 37413							
30 000	600	1 2755	2755	- 0090	-.00248	1 00248	- 0220	- 54		30,055
	700	1 3871	3871	-.0065	00252	1 00252	- 0223	- 55		30,055
	750	1 4523	4523	- 0035	- 00158	1 00158	- 0140	- 35		30,035
	800	1 5243	5243	+ 0014	+.00073	1 00073	+ 0065	+ 16		29 985
	P - 5 53801 " Hg		σ - 24617							
40 000	700	1 3871	.3871	- 0065	- 00252	1 00252	- 0139	- 52		40.050
	750	1 4523	4523	- 0035	- 00158	1.00158	- 0087	- 33		40 035
	800	1 5243	5243	+ 0014	+ 00073	1 00073	+ 0040	+ 15		39,985

FIGURE 8.8

PILOT'S AND COPILOT'S STATIC SYSTEM CALIBRATION
AIRCRAFT: REC 525Z, Serial Number Y2018Z

NOTE: Calibration Does Not Include Altimeter Instrument Error

Measured Airspeed (Knots)	True Pressure Altitude (feet) / Measured Pressure Altitude (feet): 0	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000
I. Aircraft Configuration: Clean									
200	15		10,020		20,030		30,045		
220	20		10,030		20,035		30,055		
240	25		10,030		20,045				
260	30		10,040		20,055				
280	35		10,045						
300	40		10,050						
320	45		10,060						
340	50		10,065						
360	55								
380	60								
400	70								
II. Aircraft Configuration: Partial Flaps									
160	15	5,020	10,020	15,025					
180	20	5,025	10,030	15,030					
200	25	5,030	10,035	15,040					
220	30	5,035	10,040	15,050					
III. Aircraft Configuration: Partial Flaps Plus Gear Extended									
140	5	5,005	10,005						
160	5	5,005	10,005						
180	5	5,005	10,010						
200	5	5,010	10,010						
IV. Aircraft Configuration: Full Flaps Plus Gear Extended									
120	5	5,005	10,005						
140	5	5,005	10,005						
160	5	5,005	10,005						
180	5	5,005	10,010						

V. Aircraft Configuration: Clean

Measured Mach Number	True Pressure Altitude (feet) / Measured Pressure Altitude (feet): 0		10,000		20,000		30,000		40,000
.30	20								
.40	30		10,025						
.50	45		10,045		20.040				
.60	70		10,065		20,060		30,055		
.70	70		10,065		20,060		30,055		40.050
.75	45		10,040		20,040		30,035		40,035
.80	-20		9,980		19,985		29,985		39,085

SECTION 9

LIST OF SYMBOLS

b	=	Wing span, feet
C_L	=	Lift coefficient
C_{Lm}	=	Measured Lift coefficient
f	=	Focal length of camera, inches
g	=	Acceleration due to gravity at a point, feet/second^2
G	=	Gravitation constant, 32.17405 feet^2/second^2 - geopotential feet
h	=	Tapeline altitude; height, feet
H	=	Geopotential pressure altitude, feet, corresponding to true static pressure, p
H_i	=	Uncorrected altimeter reading, feet
H_m	=	$H_i + \Delta H_{ic}$, Measured pressure altitude, feet
ΔH	=	H_m - H, Altimeter position error, feet
ΔH_c	=	H - H_m, Altimeter position error correction, feet
ΔH_{ic}	=	$H_m - H_i$, Altimeter instrument correction, feet
M	=	True flight Mach number
M_i	=	Uncorrected Machmeter reading
M_m	=	$M_i + \Delta M_{ic}$, Measured Mach number
ΔM	=	M_m - M, Measured Mach number error
ΔM_c	=	M - M_m, Machmeter position error correction
ΔM_{ic}	=	$M_m - M_i$, Machmeter instrument correction
n	=	Load factor (n = 1 when aircraft Lift equals gross weight)
p	=	True static pressure, inch Hg
p_m	=	Measured static pressure, inch Hg

List of Symbols - Continued

Δp = $p_m - p$, inch Hg

p_t = True or free stream total pressure, inch Hg

$p_{t'}$ = True pitot pressure, inch Hg, $p_{t'} = p_t$ for $M \leq 1$ and $p_{t'} = p_t$ behind a normal shock for $M > 1$

$p_{t'm}$ = Measured pitot pressure, inch Hg

$\Delta p_{t'}$ = $p_{t'm} - p_{t'}$, inch Hg

q = $1/2\ \rho\ V^2 = \frac{\gamma}{2}\ p\ M^2$, incompressible dynamic pressure, inch Hg

q_m = $\frac{\gamma}{2}\ p_m\ M_m{}^2$, inch Hg

q_c = $p_{t'} - p$, Impact pressure or compressible dynamic pressure, inch Hg

q_{cm} = $p_{t'm} - p_m$, inch Hg

T = Static temperature, °R

T_r = Recovery temperature, °R

T_t = True or free stream total temperature, °R

V = True airspeed (TAS), Knots

V_c = Calibrated airspeed, Knots

V_i = Uncorrected airspeed indicator reading or indicated airspeed (IAS), Knots

V_m = $V_i + \Delta V_{ic}$, Measured airspeed, Knots

ΔV = $V_m - V_c$, Measured airspeed error, Knots

ΔV_c = $V_c - V_m$, Airspeed indicator position error correction, Knots

ΔV_{ic} = $V_m - V_i$, Airspeed indicator instrument correction, Knots

W = Aircraft gross weight, pounds

α = Attack angle, degrees

List of Symbols - Concluded

α_1	=	Local attack angle, degrees
β	=	Sideslip angle, degrees
β_1	=	Local sideslip angle, degrees
γ	=	Ratio of specific heats, approximately 1.4 for air
δ_m	=	$p_m/p_{m_{s1}}$
ρ	=	True air static density, lb/ft^3
ρ_{s1}	=	True air static density at standard sea level conditions, lb/ft^3
σ	=	ρ/ρ_{s1}, Relative density

SECTION 10

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APPENDIX A

DESCRIPTION AND OPERATING PRINCIPLES OF STATIC PORT CALIBRATORS

APPENDIX A

DESCRIPTION AND OPERATING PRINCIPLES OF STATIC PORT CALIBRATORS

1. INTRODUCTION

Static port calibrators are used for precise measurements of static pressure position errors on aircraft. term "static port calibrator" is arbitrary, and is used in this report to cover a class of instruments incorporating precision limited range differential pressure transducers. The differential pressure transducer has one side connected to the aircraft's static pressure source and the other side connected to a reference pressure. A calibrator operates much like a narrow range altimeter.

Two types of calibrators are described in this report:

(1) The first type has an internal reference pressure chamber of constant volume which is accurately maintained at a constant temperature and, therefore, constant pressure. This design is often called a "statoscope" and in early applications was used primarily as a level flight indicator. For flight calibration of an aircraft's static pressure ports the reference chamber in the calibrator is sealed at some pre-selected reference pressure altitude and flight condition. The differential pressure gage then measures the change or deviation of the aircraft's static pressure with respect to the reference pressure. The calibrator is used in the "Camera Fly-Over", "Radar Tracking", and "Pacer Aircraft" flight calibration procedures, described in detail in Sections 4, 5, and 6 of the main report.

(2) The second type of calibrator is a limited range differential pressure instrument used with the Trailing Cone flight calibration procedure, Section 7 of the main report. It is intended for precise measurement of small differences

between the aircraft's static pressure and static pressure measured by the trailing cone.

2. STATIC PORT CALIBRATOR WITH INTEGRAL REFERENCE PRESSURE CHAMBER

A typical calibrator consists of components presented schematically in Figure A1. A small volume reference pressure chamber is maintained at constant temperature by use of a temperature controller. This chamber is connected to the aircraft static pressure system. A reference air sample is stored by closing a valve at the chamber inlet. The limited range differential pressure gage is located adjacent to the reference chamber so it is maintained also at constant temperature. One side of the gage is exposed to the reference chamber and the other side is vented to the aircraft static port. A photograph of a unit of one specific design is shown in Figure A2. A system block diagram for this unit is given on Figure A3.

An "Observer's" meter located on the calibrator and a remote "Pilot's" meter can provide both the operator and the pilot with visual reference of the pressure difference between the static pressure system of the aircraft and the reference tank. A typical meter is shown on Figure A4. The output signal is of positive polarity when the "AIRCRAFT" pressure is higher than the "REFERENCE" pressure. Full scale reading of the meter is ± 0.200 inches of mercury. A selector switch on the calibrator can reduce the full scale sensitivity of the "Observer's" meter. The switch used in the unit on Figure A2 is shown schematically on Figure A3. For this design, switch position (X1) gives a full scale range of ± 0.200 inches Hg, (X2) for ± 0.400" Hg, (X3) for ± 0.600" Hg, (X4) for ± 0.800" Hg, and (X5) for ± 1.000" Hg full scale for the front panel meter.

A calibrator can also provide an output voltage signal for a recording oscillograph. A continuous and permanent recording of the differential pressure is sometimes desirable and might be necessary for high speed flight calibration.

Inflight calibration checks for the output voltage signal and the visual meters are desirable. For the unit shown on Figure A3, a manual switch provides a zero pressure differential

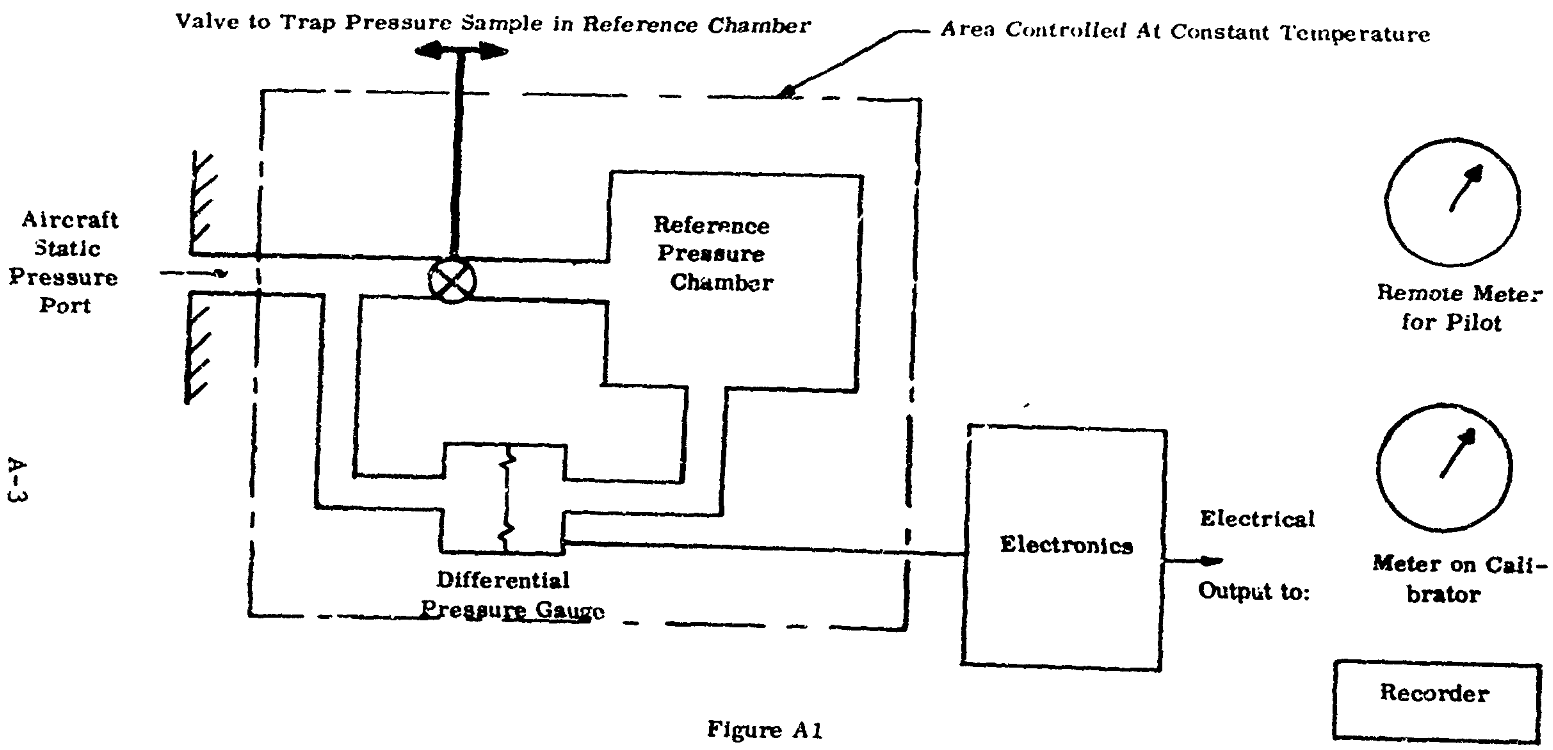


Figure A1

Schematic of Static Port Calibrator with Integral Reference Pressure Chamber

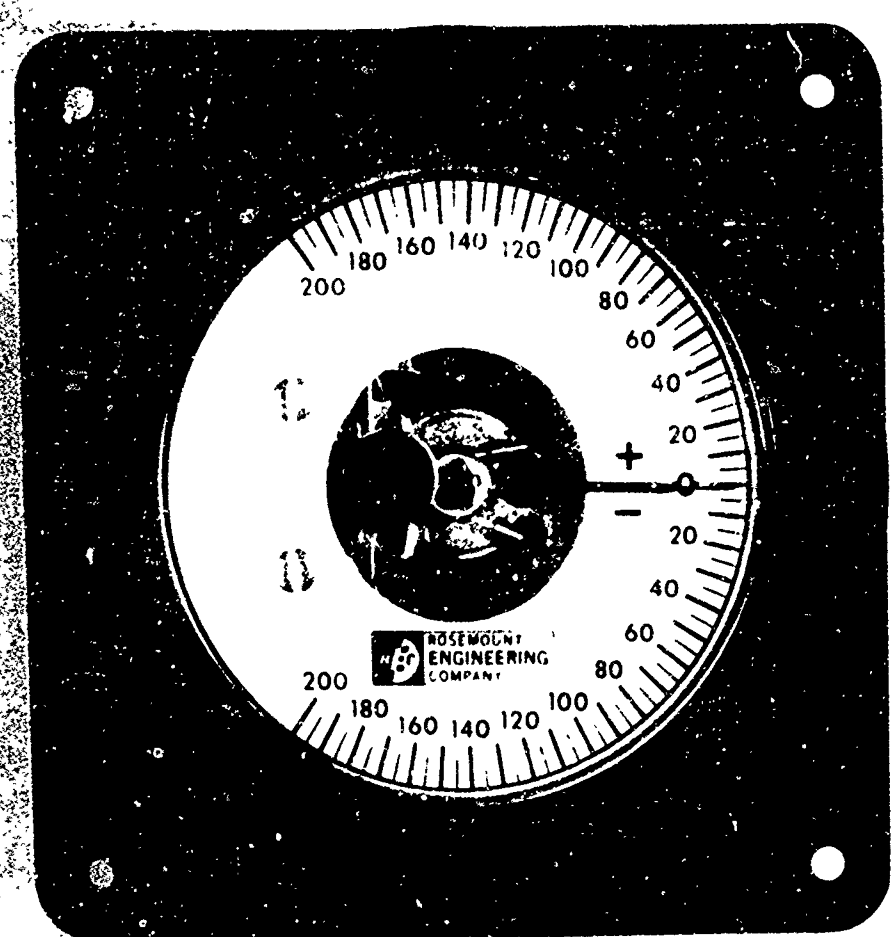


Figure A2

Static Port Calibrator
With Integral Reference Pressure
Chamber

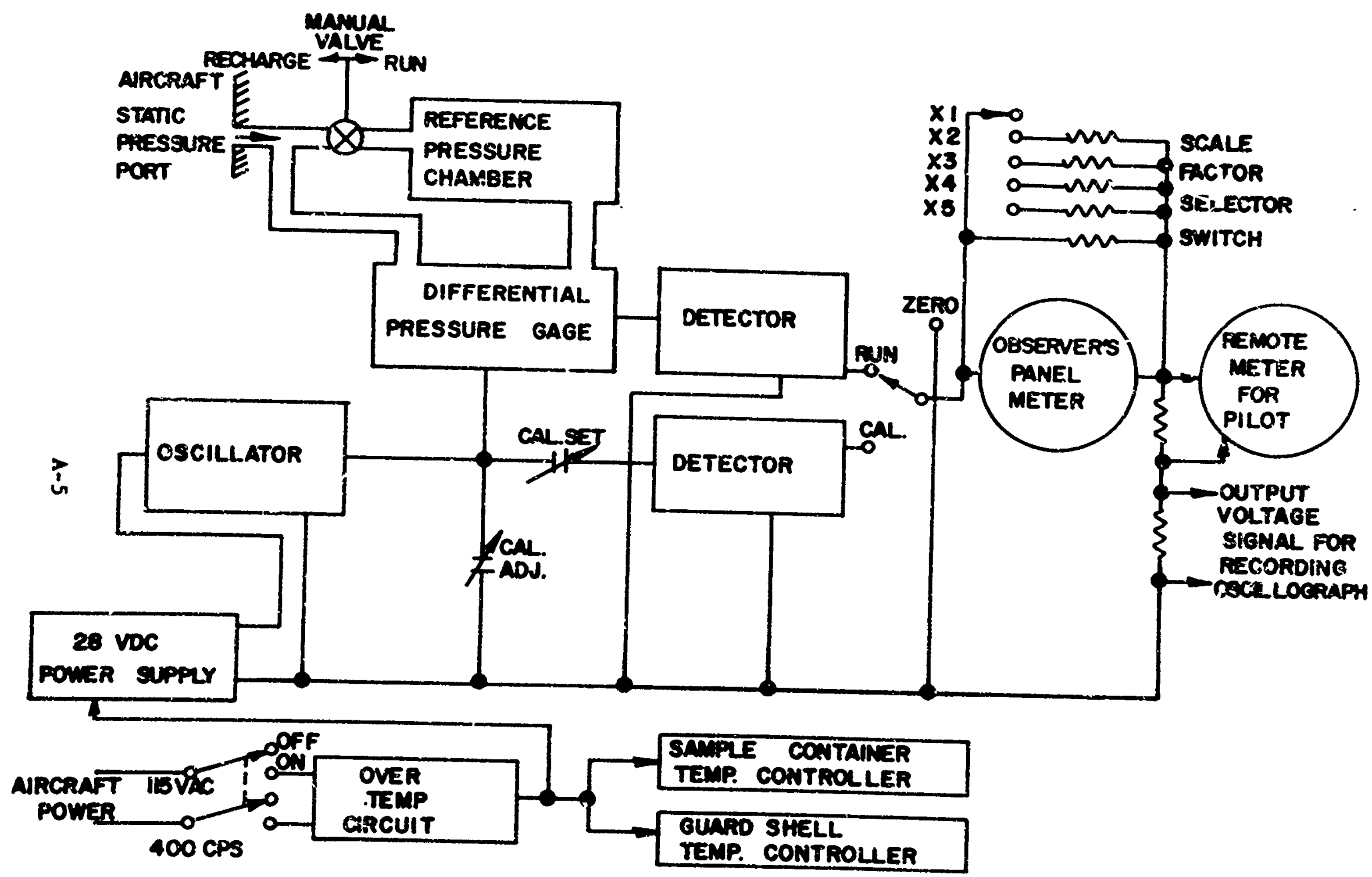


Figure A3

System Block Diagram
Static Port Calibrator with Integral Reference Pressure Chamber

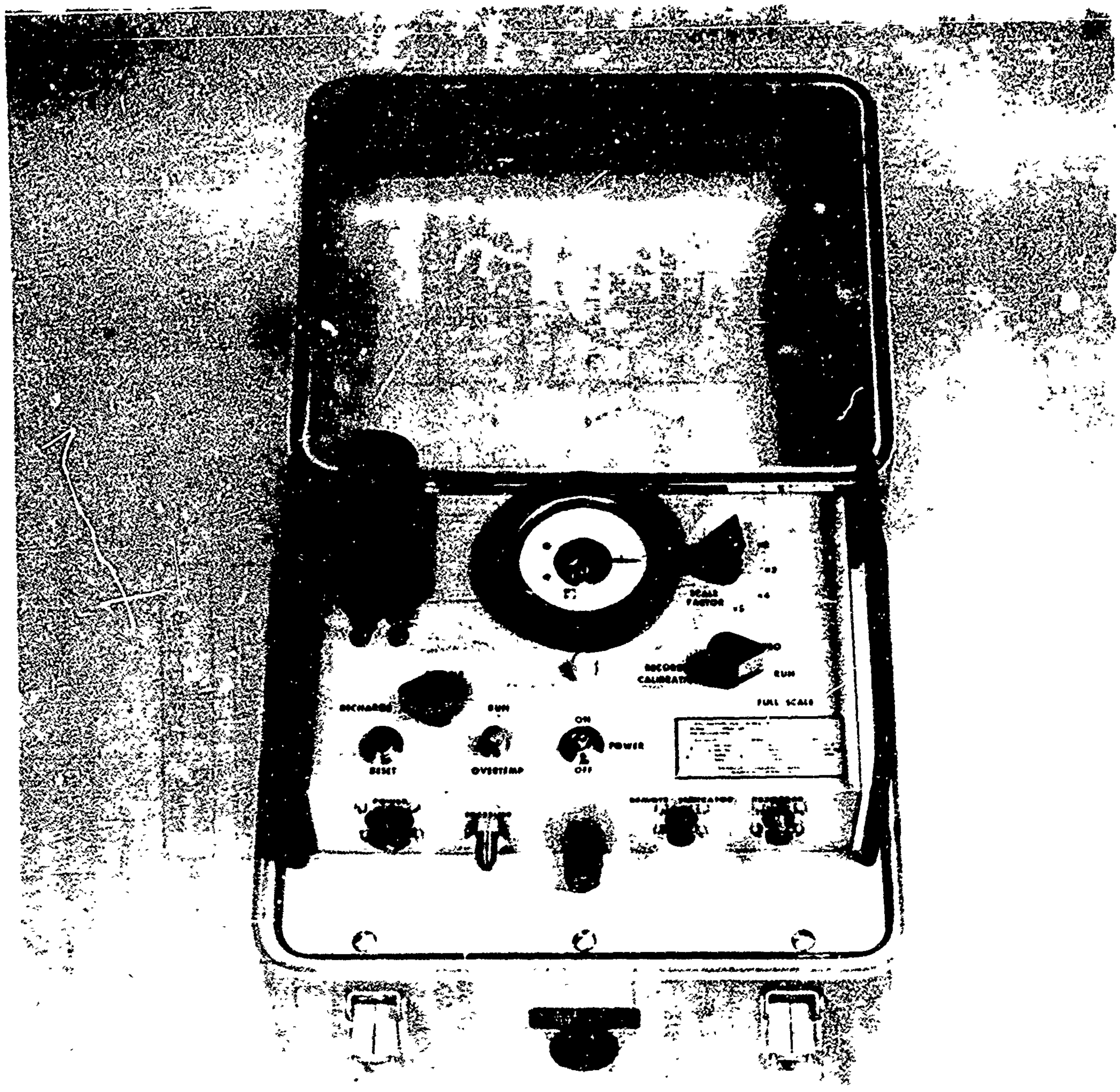


Figure A4

Remote "Pilot's" Meter

signal and a calibrate signal which corresponds to a pressure differential of +0.200" Hg. These two signals are useful in checking performance of the calibrator during the flight test operation.

In one design of a static port calibrator, a limited range electric capacitance type pressure gage is utilized. Primary full scale range is ±0.5" Hg (±0.25 psid) for initial pressures between 0 and 20 psia. This provides an equivalent altitude range of about ±500 feet at sea level and the range increases with increasing altitude. The gage also provides a usable voltage output signal for an extended range of about ± 1" Hg (±0.5 psid) and is designed to withstand overpressures to 25 psid without calibration shift. Typical accuracies of a calibrator using a pressure sensor of this type are evaluated in Section 3.2.3 of the main report.

2.1 Operating Instructions

Step-by-step operating procedures for a static port calibrator with integral reference pressure chamber are described in the following paragraphs.

(1) Meter Zero Check: With the instrument in normal mounting position and power off, check zero on both the Pilot's meter and the Observer's meter and adjust if necessary.

(2) Warm-Up Period: Turn power on and allow reference pressure chamber to come to complete temperature equilibrium.

(3) Zero Check: With the pressure sealing valve in the open position (to establish zero differential across the pressure gage), both meters should read less than 0.001 inch Hg. An output signal greater than ± 0.001 inch Hg indicates the need for recalibration, per Section 2.2 below, by the manufacturer or at a field repair laboratory.

If a recording oscillograph is used, the zero trace should also be recorded at this time.

(4) Zero Calibration Check: At the zero calibration setting, both meters should read less than 0.001 inch Hg. A larger output indicates the need for recalibration. The zero reading should remain constant on each meter for all scale factor switch settings.

A zero calibrate trace should also be recorded on the recording oscillograph at this time.

(5) Full Scale Calibration Check: At the full scale calibration setting, the corrected reading of the "Observer's" Panel Meter should be within ± 0.001 inch Hg of the full scale signal. A larger error indicates the need for recalibration of the instrument.

The calibrate trace is also recorded on the recording oscillograph at this time. The gain of the recorder can be adjusted, if necessary.

(6) In-Flight Operation: Detailed operating procedures, described in Sections 4, 5, and 6 of the main report, vary according to the method of static system calibration being used. In general, the operation of the calibrator consists simply of closing the reference pressure chamber valve at the desired reference static pressure and recording data. It is desirable to perform in-flight calibration before and after each data point.

2.2 Laboratory Pressure Calibration

The static port calibrator is a precision instrument capable of accurately measuring small pressure differentials. To maintain the high degree of accuracy needed for reliable flight test results, special calibration methods must be employed. Laboratory calibration procedures for a static port calibrator with integral reference pressure chamber are described in the following paragraphs.

(1) Meter Zero Check: With the instrument in normal mounting position and power off, check zero on both the Pilot's meter and the Observer's meter and adjust if necessary.

(2) Warm-Up Period: Turn power on and allow reference pressure chamber to come to complete temperature equilibrium.

(3) Zero Check: With the pressure sealing valve in the open position (to establish zero pressure differential across the sensor), adjust zero calibrate signal for both meter signals and the output voltage signal, if necessary, to read less than ± 0.001 inch Hg. Do not disturb mechanical zero on meters. Check zero readings at all scale factor switch settings and adjust, if necessary, so that both meter readings and the output voltage signal remain at zero at all switch settings.

(4) Long Term Stability Check: Connect a pressure measuring standard to the static pressure port connector on the calibrator. Evacuate reference pressure chamber to about 15 inch Hg absolute, (equivalent to 17,900 feet pressure altitude). Maintain constant pressure within ±0.001 inch Hg for 10 minutes; then seal reference pressure sample. Decrease pressure in the static port connector line to 0.100 inch Hg below the trapped reference pressure value. Maintain this pressure constant within ± 0.001 inch Hg absolute accuracy for a period of at least two hours. Record readings of the "Observer's" Panel Meter every 5 minutes. Also record output voltage signal on a sensitive differential voltmeter. All readings taken over the two hour period should remain within ± 0.002 inches Hg. Readings deviating by more than ± 0.002 inches Hg could be caused by a pressure leak in the calibrator, temperature instability of the reference pressure chamber, or instability of the pressure gage.

Pressure check the connecting pressure tubing in the calibrator after the two-hour stability test by leaving the trapped pressure sample in the unit and maintaining a pressure of about 15 inches Hg absolute in the external static port connector line. Then seal off the source of vacuum to the static port connector line. The change in panel meter reading shall not exceed 0.020 inch Hg per minute over a five minute period.

(5) Zero Calibration Check: After the long term stability test, the pressure sample is released and the pressure is returned to existing barometric conditions. At a zero calibration setting, both meter signals and the voltage output

signal should read less than 0.001 inch Hg; adjust if necessary. Do not disturb mechanical zero on meters. The readings should remain constant for all scale factor switch settings.

(6) Full Scale Calibration Check: Connect a pressure measuring standard to the static pressure port connector on the calibrator and establish barometric pressure in the calibrator's reference pressure chamber. Close the valve to trap a reference pressure sample. Adjust the applied pressure if necessary, to establish zero differential across the pressure gage. Zero differential is obtained when the Observer's meter reads zero. From this zero value, apply a differential pressure equal to the full scale calibrate signal within ± 0.001 inch Hg. Then adjust calibrate signal for exactly this same full scale deflection on "Observer's" panel meter.

Output voltage signal of the instrument at the full scale calibration point should also be recorded during the above calibration check.

(7) Pressure Gage Calibration: To determine correction charts for the two visual meters and the output voltage of the calibrator, apply accurately known pressure inputs after completing the foregoing calibration adjustments. Applied pressure differentials must be accurate to ± 0.001 inch Hg. Readings should be recorded in both the positive and negative pressure differential regions. Suggested points of measurement are 0, ±0.05, ±0.1, ±0.15, ±0.2, ±0.3, ±0.4, ±0.5, ±0.6, ±0.8, and ±1.0 inch Hg. Close to existing barometric pressure should be trapped in the reference pressure chamber during the calibration. Corrections for the two meters and for the output voltage, or the oscillograph trace, are plotted as the value to be added to the reading to give the correct output. Examples of correction charts are given on Figures A7 and A8.

3. STATIC PORT CALIBRATOR FOR USE WITH TRAILING CONE

A calibrator for use with the trailing cone method of flight calibration has a limited range differential pressure gage to measure the difference between the trailing cone reference static pressure and pressure measured by the aircraft's static ports. The output signal is of positive polarity when

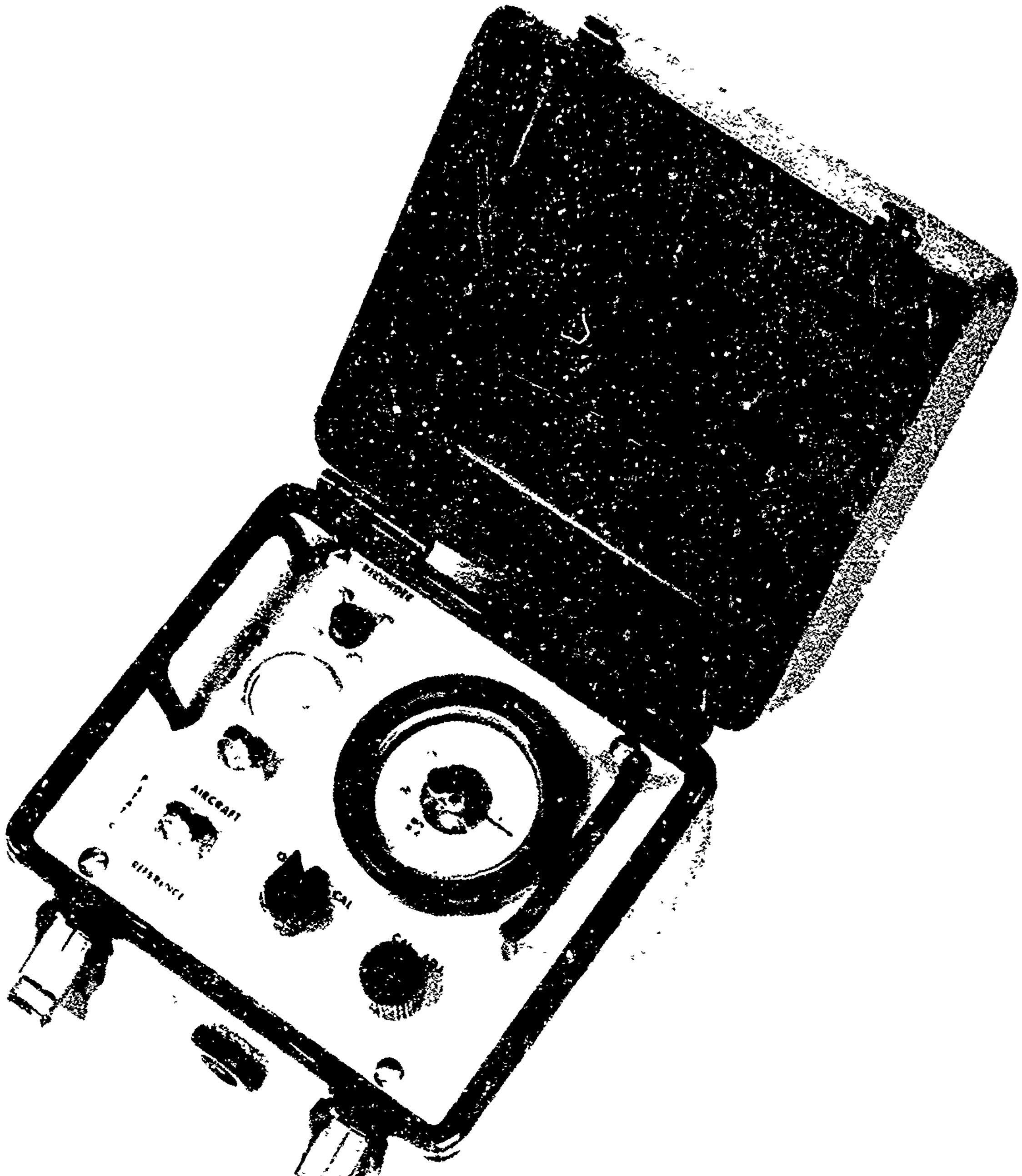


Figure A5

Static Port Calibrator for Use with Trailing Cone

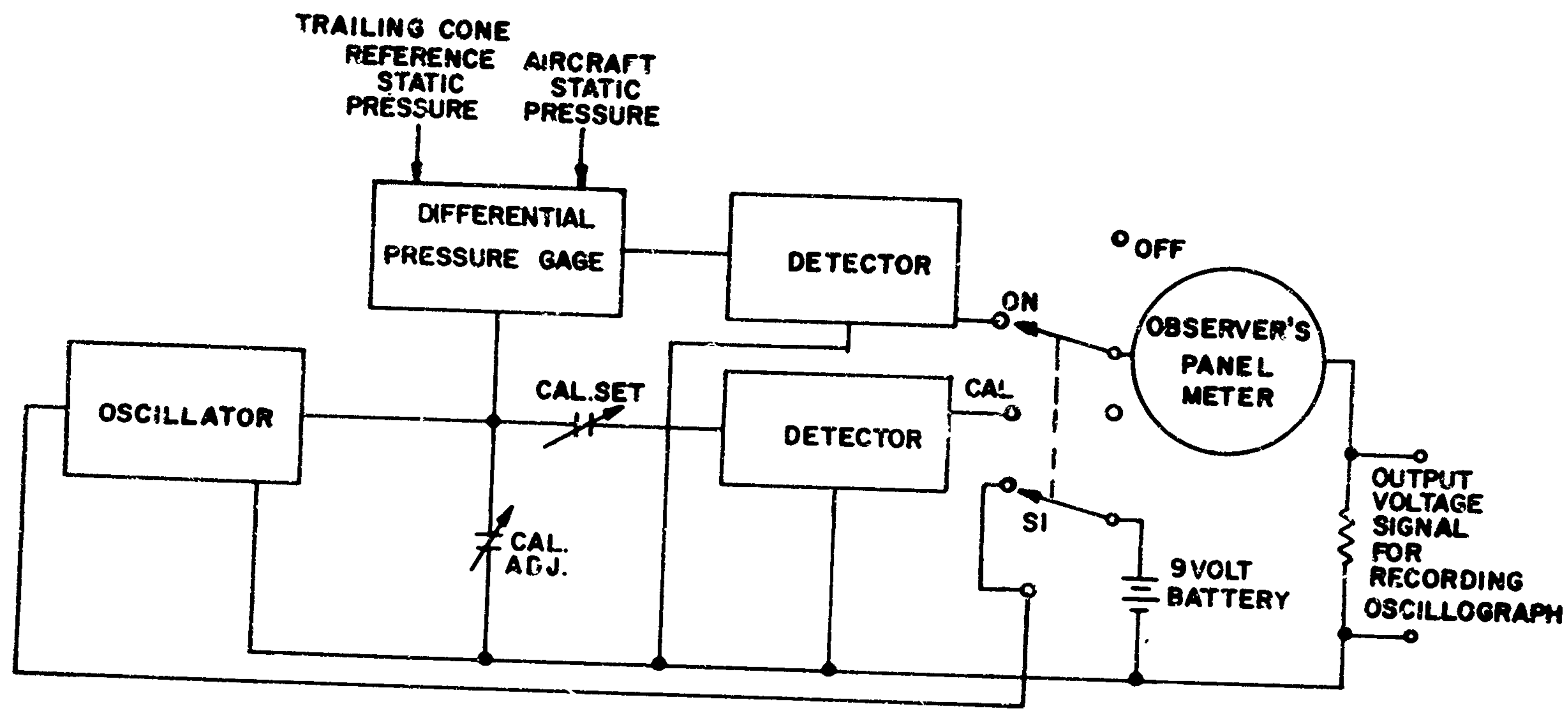


Figure A6

System Block Diagram
Static Port Calibrator for use with Trailing Cone

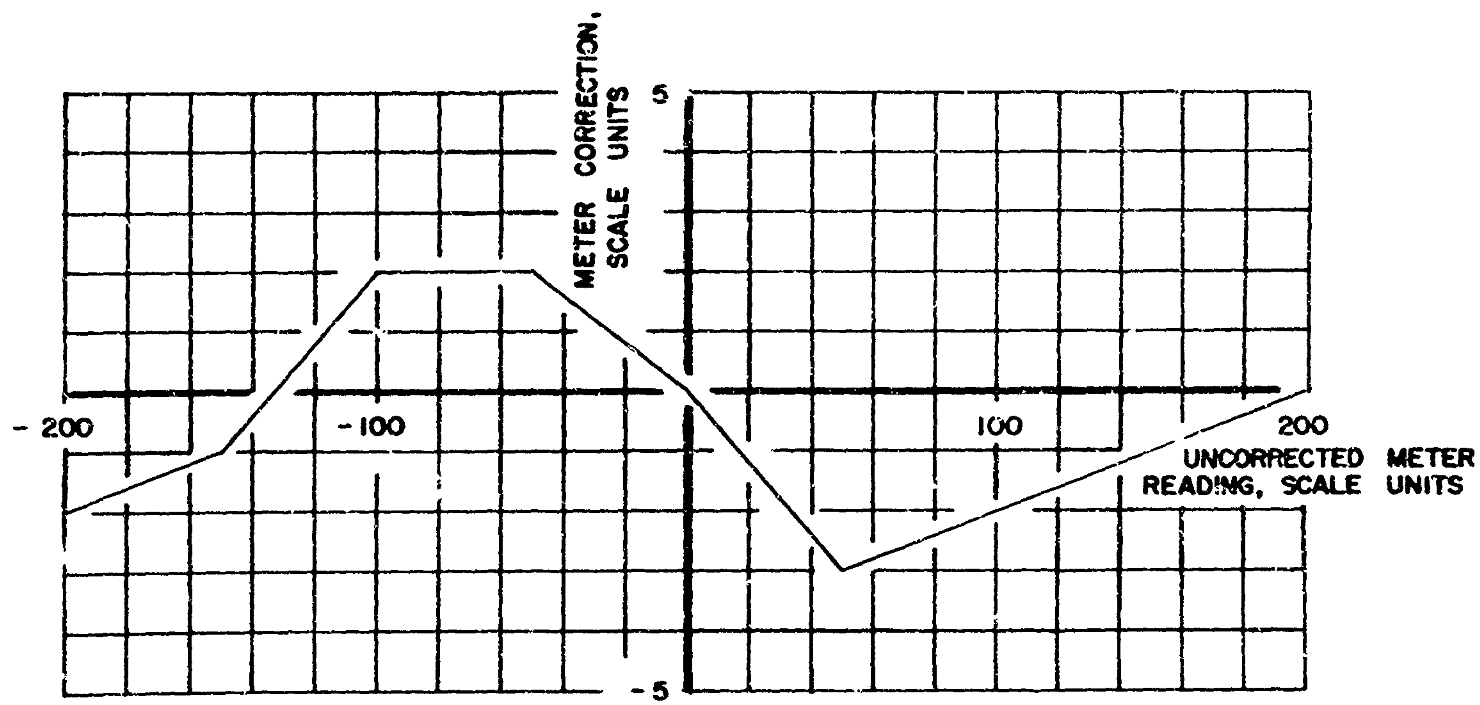


FIGURE A7

TYPICAL CALIBRATION CURVE OF STATIC PORT CALIBRATOR

METER CORRECTION VS. METER READING

(UNCORRECTED METER READING) + (METER CORRECTION) = (CORRECTED METER READING)

CONVERSION CONSTANT FOR CORRECTED METER READING = .001 IN. HG/SCALE UNIT

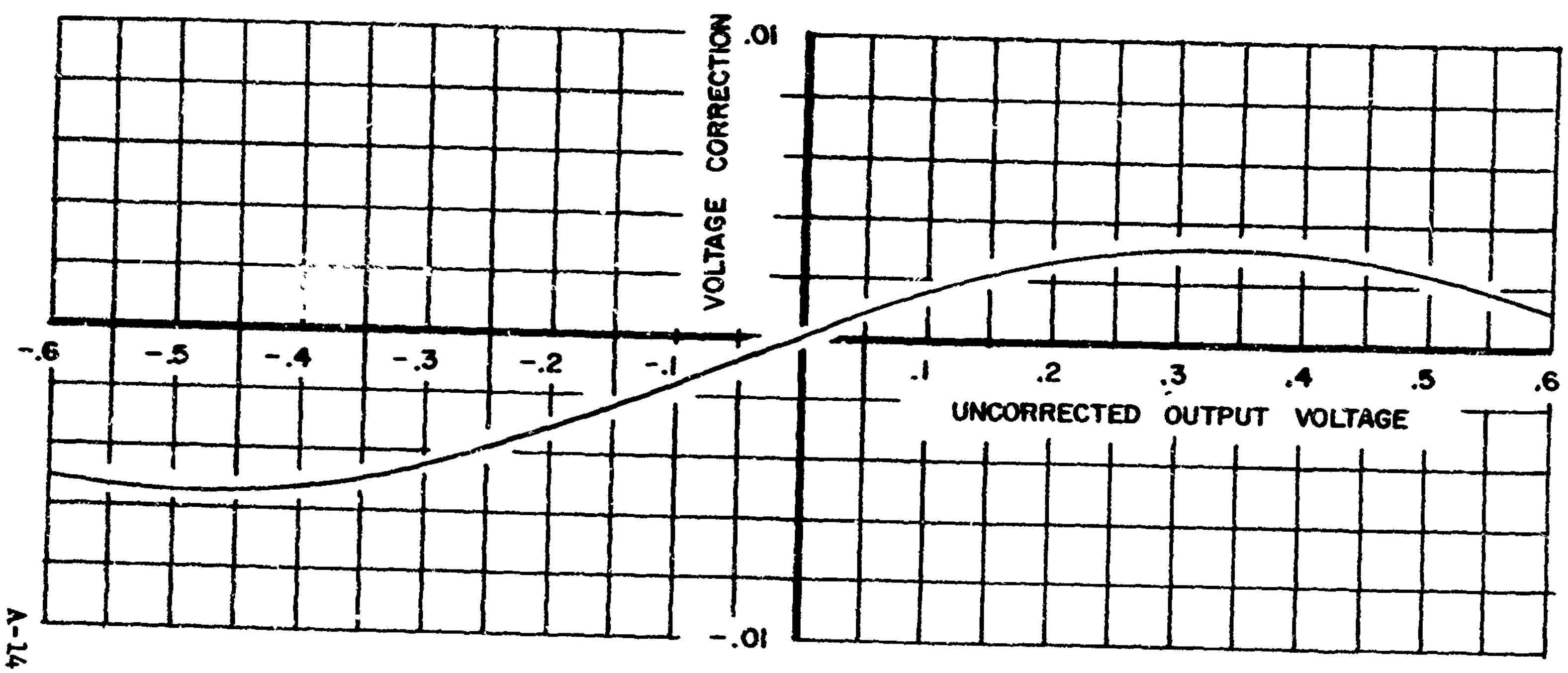


FIGURE A8

TYPICAL CALIBRATION OF STATIC
PORT CALIBRATOR

VOLTAGE CORRECTION VS. OPEN CIRCUIT OUTPUT VOLTAGE

(UNCORRECTED VOLTAGE OUTPUT) + (VOLTAGE CORRECTION) = (CORRECTED VOLTAGE OUTPUT)

CONVERSION CONSTANT FOR CORRECTED VOLTAGE OUTPUT = 1.5 VOLTS/IN. HG

the "Aircraft" pressure is higher than the "Reference" pressure. Output signals, proportional to the difference of the two applied pressures, may be read directly from a panel meter or may be used to drive an external meter or voltage recorder such as a recording oscillograph. Inflight calibration checks for the output voltage signal and meters are desirable. A photograph of a portable, battery operated unit of one specific design is shown on Figure A5. A system block diagram for this unit is given in Figure A6. Full scale reading on the panel meter is ±0.200 inch Hg.

In one design of a calibrator for use with the trailing cone method, a limited range electric capacitance type pressure gage is utilized. Primary full scale range is ± 0.5" Hg (0.25 psid) for initial pressures between 0 and 20 psia. This provides an equivalent altitude range of about ± 500 feet at sea level and the range increases with increasing altitude. This gage also provides a usable voltage output signal for an extended range of about ± 1" Hg (± 0.5 psid) and is designed to withstand overpressures to 25 psid without calibration shift. Typical accuracies of a calibrator using a pressure sensor of this type are evaluated in Section 3.2.3 of the main report.

3.1 Operating Instructions

This section deals only with the operation of the static port calibrator. The manner in which the unit is to be used as a flight calibration device is discussed in Section 7 of the main report.

Before the instrument is ready for operation, its calibration should be checked. Calibration is done as follows:

(1) With power off and the unit in normal mounting position, check the panel meter zero, and adjust if necessary. Tap meter lightly for an accurate reading.

(2) Turn unit on.

(3) Apply equal pressures to the pressure fittings for the trailing cone reference static pressure and the aircraft static pressure. This may be accomplished by opening both

fittings to atmospheric pressure or connecting both fittings to the same pressure line. This could be done prior to connecting pressure fittings as part of pre-flight preparations. With equal pressure applied, the meter and/or recorder should indicate the zero pressure difference. An output signal greater than ± 0.001 inch Hg indicates the need for recalibration, per Section 3.2 below, by the manufacturer or at a field repair laboratory.

(4) If the unit has a calibrate signal, record signal on meter and/or recorder. Calibration signal should be accurate within ± 0.001 inch Hg. The gain of the recorder can be adjusted at this time, if necessary.

3.2 Laboratory Pressure Calibration

The static port calibrator is a precision instrument capable of accurately measuring small pressure differentials. To maintain the high degree of accuracy needed for reliable flight test results, special calibration methods must be employed. Laboratory calibration procedures for the static port calibrator are described below.

(1) With the power off and the unit in normal operating position, adjust meter for exactly zero, tapping lightly for an accurate reading.

(2) Allow unit to warm up and stabilize.

(3) With static ports connected together by a short length of pressure line, adjust zero output as measured on the meter or on the output voltage.

(4) Apply to the static ports a full scale differential pressure accurate to better than ± 0.001 inch Hg. Adjust unit for exactly full-scale deflection on meter.

(5) With pressure still maintained at the pressure ports, adjust calibrate signal for exactly full scale deflection on meter.

(6) To determine correction charts for the panel meter and the output voltage of the calibrator, apply accurately known pressure inputs after completing the foregoing calibration adjustments. Applied pressure differentials must be <u>accurate to ± 0.001 inch Hg</u>. Readings should be recorded in both the positive and negative pressure differential regions. Suggested points of measurement are: 0, ±0.05, ±0.1, ±0.15, ±0.2, ±0.3, ±0.4, ±0.5, ±0.6, ±0.8, ±1.0, inch Hg. Corrections for the panel meter and output voltage, or the oscillograph trace, are plotted as the value to be <u>added</u> to the <u>reading</u> to give the correct output. Examples of correction charts are given on Figures A7 and A8.

APPENDIX B

RECOMMENDED TEST PROCEDURE FOR PRECISION ALTIMETER USED IN "FULL RANGE ALTIMETER" CAMERA FLY-OVER CALIBRATION PROCEDURE (Section 4.3.1)

1. INTRODUCTION

A precision altimeter can be used to determine pressure altitude for Camera Fly-Over flight calibration of low speed aircraft with limited altitude capabilities. The altimeter errors must be small and well defined over a very limited altitude band, -1000 feet to +3000 feet in pressure altitude from the ground test site elevation at which the altimeter is to be used. A recommended test procedure for evaluating accuracy of the altimeter and for calibrating scale errors is presented below. The altimeter shall be calibrated within 10 days prior to use. A calibration chart of altimeter instrument correction (ΔH_{ic}) vs uncorrected altimeter reading (H_i) shall be made from results of the Scale Error Test, Paragraph 3.5 and Table II.

2. GENERAL

2.1 Standard Atmosphere.

The ICAO Standard Atmosphere (NASA Report 1235, Reference 6) shall be used to obtain static pressure as a function of pressure altitude. A table covering the altitude range needed is included in Table C-I in Appendix C.

2.2 Reference Standard Barometer.

The reference standard for atmospheric pressure shall be a Hass Type A-1 Mercury Barometer, or equivalent. Minimum accepted standards for the barometer, including operation and maintenance procedures, shall conform to the requirements of Appendix IV of Reference 41 (Section 10). A continuous vacuum pumping system shall be connected to the reference vacuum side of the barometer. Suitable means shall be made for monitoring the reference pressure. The barometer shall be compared to the standard of the NBS at least once every two years by a competent source and shall be accurate, with corrections, to within 0.005 inch Hg. A reference barometer, newly introduced into service, should be checked at intervals of approximately six months, until the stability of its calibration has been established.

Note: It should be noted that unless extreme care is taken in setting and reading the reference barometer, the error introduced may exceed some of the tolerances specified in this test procedure.

2.3 Temperature During Tests.

Unless otherwise specified, all tests should be carried out in a temperature of +20°C ± 5°C. When tests are conducted with temperatures substantially different from this value, a correction shall be made for the variation fr the specified condition.

2.4 Pressure Datum During Tests.

All tests shall be carried out with the pressure scale of the altimeter set at 29.92 in. Hg. (1013.25 mb).

2.5 Reading.

Unless otherwise specified, each reading shall be taken approximately 1 minute after the reference pressure is stabilized.

NOTE: The period of 1 minute has been specified to simulate as closely as possible conditions encountered in actual flight operations.

2.6 Vibration. (to minimize friction).

Unless otherwise specified, all tests shall be made while the instrument is subjected to vibration. Vibration shall be applied by means of electromechanical vibrators or a vibration stand. Tapping the instrument for the purpose of removing the friction is unacceptable. Sufficient vibration should be applied to remove all friction from the instrument.

NOTE: This should be of the order of 0.2 g and is, for instance, attainable with a vibration of 0.04 mm total amplitude at a frequency of 50 cycles per second. A frequency less than 50 cycles per second is not recommended. Vibrators should be of the shock type.

2.7 Sequence of Tests.

The sequence of the tests listed below is recommended but is not mandatory.

3. TEST PROCEDURES

3.1 Case Leak Test.

The pressure connection of the altimeter case shall be sealed at ambient pressure and the altimeter placed in a test chamber. The chamber pressure shall be decreased to 14.94 in. Hg absolute.

The change in height indication shall not exceed 50 ft per minute over a five-minute period.

3.2 Position Error.
The altimeter reading shall be taken while the altimeter is in a vertical 12 o'clock position (dial up) and after it has been vibrated. The altimeter shall then be rotated 90° to its normal operating position (3 o'clock). Readings shall be taken after vibration, in the 12, 3, 6, and 9 o'clock positions. None of the readings shall differ from the 12 o'clock reading by more than 20 feet. This test shall be conducted with the altimeter mounted in a test fixture, which, with a fixed base, can be used to rotate the altimeter to each desired position. A vibrator of the type specified in paragraph 2.6 shall be strapped to the instrument case for the purpose of removing the friction and shall remain in this position for the duration of the test. The amount of vibration applied shall be sufficient to remove all friction from the instrument.

3.3 Friction.
Part of this test is performed without vibrating the instrument. With no vibration applied, increase the pressure at a rate of 100 feet per minute until it has reached a value corresponding to the first altitude shown in Table I. Read the instrument. Without changing the pressure equivalent of the altitude at the test point, apply vibration and take a second reading. Repeat this procedure for each of the altitudes shown in Column 1 of Table I. The difference between the two pointer indications, before and after vibration, shall not exceed the figures listed in Column 2.

Without vibration being applied to the altimeter when the pressure is changed uniformly between test points, the movement of the pointers shall be observed for backlash or any irregular motion. The pointer shall not stop and jump by more than 40 feet.

TABLE I

Friction

Altitude[a] Feet	Tolerance Feet
-1000	70
- 500	70
0	70
500	70
1000	70
1500	70
2000	70
2500	70
3000	70

Note: (a) Pressure altitude minus ground test site elevation (to nearest 100 feet) at which the altimeter will be used, see Section 4.2 of main report.

3.4 Temperature Reading

Note the reading of the altimeter under the ambient conditions. Place the altimeter in an oven, maintained at +70°C ± 2°C for one hour. The oven must be vented to the atmosphere with several holes of at least one-half inch in diameter. The high temperature reading shall be within forty (40) feet from the room reading after corrections are made for ambient variations. If it is convenient, the tester may connect the altimeter to a barometer for these readings using an altitude of zero feet for this test.

Note: Under no conditions should the barometer be connected to the instrument in the oven for a period longer than that necessary for reading. The altimeter shall be rechecked at ambient temperature after this test to insure the accuracy of these data.

3.5 Scale Error and Hysteresis

The scale error test shall be conducted with the altimeter in an altitude or vacuum chamber. For a period of not less than twelve hours prior to this test, the altimeter shall not have been operated at other than atmospheric pressure. The barometric

pressure scale shall be set at 29.92. While the altimeter is ..b'ected to atmospheric pressure, the reading of the pointers ... taken and the error of this indication determined by ...ion with a barometer. This error shall be used later in ... specified in Paragraph 3.6. Without changing the ..., the altimeter shall be subjected successfully to the pressures corresponding to each test point specified in Table II.

Increasing the pressure to point (1) at the start of the test shall not exceed 500 feet per minute. The decrease in pressure from points (1) through (21) and the increase in pressure from points (22) to (42) shall not exceed 100 feet per minute. Pressure at each test point shall be approached from the correct side and shall not cross over the test point value prior to the time of reading. The altimeter shall remain at the pressure corresponding to each test point for at least 1 minute, but not more than 3 minutes, before a reading is taken. Pressure is held constant for 30 minutes before reading altimeter at the ends of the hysteresis loop, points (1) and (22). After the reading of point (42), the pressure shall be returned to atmospheric pressure at the rate of 500 feet per minute. The error at all test points shall not exceed ± 30 feet.

The altimeter instrument correction (ΔH_{ic}) is the average of the altimeter scale errors for each side of the hysteresis loop, Columns (5) and (7) on Table II. The difference between upscale and downscale readings at each test altitude shall not exceed ± 30 feet.

3.6 After Effect.

Not less than 1 minute nor more than 5 minutes after the completion of the test specified in Paragraph 3.5, the pointers shall have returned to their original atmospheric readings, corrected for any change in atmospheric pressure, within an allowable tolerance of ± 30 feet.

TABLE II

SCALE ERROR AND HYSTERESIS AND DETERMINATION OF ALTIMETER INSTRUMENT CORRECTION (ΔH_{ic})

(1) Altitude[(a)] (feet)	(2) H Pressure Altitude[(b)] (feet)	(3) Pressure[(c)] (Inches Hg)	(4) Test Point	(5) Increasing Altimeter Reading (feet)	(6) Test Point	(7) Decreasing Altimeter Reading (feet)	(8) H_i $\frac{(5)+(7)}{2}$ (feet)	(9) ΔH_{ic} (2)-(8) (feet)
-1000			1[(d)]		42			
- 800			2		41			
- 600			3		40			
- 400			4		39			
- 200			5		38			
0			6		37			
200			7		36			
400			8		35			
600			9		34			
800			10		33			
1000			11		32			
1200			12		31			
1400			13		30			
1600			14		29			
1800			15		28			
2000			16		27			
2200			17		26			
2400			18		25			
2600			19		24			
2800			20		23			
3000			21		22[(d)]			

NOTES: (a) Pressure altitude minus ground test site elevation (to the nearest 100 feet) at which altimeter will be used, see Section 4.2 of main report.

(b) Altitude in Column (1) plus ground test site elevation, (to the nearest 100 feet).

(c) Pressure in the standard atmosphere corresponding to altitude in Column (2), from Table C-I in Appendix C.

(d) Hold pressure constant for 30 minutes before taking test points 1 and 22.

TABLE C-I

STANDARD ATMOSPHERE TABLES
(From Reference 6)

MEASURED STATIC PRESSURE (P_m) AS A FUNCTION OF
MEASURED GEOPOTENTIAL ALTITUDE (H_m)

H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)
-5000	35.[illegible]82	-2000	32.1481	1000	28.8557
-4900	35.6135	-1900	32.0336	1100	28.7508
-4800	35.4892	-1800	31.9195	1200	28.6463
-4700	35.3652	-1700	31.8057	1300	28.5421
-4600	35.2416	-1600	31.6923	1400	28.4382
-4500	35.1183	-1500	31.5792	1500	28.3345
-4400	34.9954	-1400	31.4664	1600	28.2312
-4300	34.8728	-1300	31.3539	1700	28.1282
-4200	34.7506	-1200	31.2418	1800	28.0255
-4100	34.6287	-1100	31.1300	1900	27.9231
-4000	34.5072	-1000	31.0185	2000	27.8210
-3900	34.3860	- 900	30.9073	2100	27.7193
-3800	34.2651	- 800	30.7965	2200	27.6178
-3700	34.1446	- 700	30.6860	2300	27.5166
-3600	34.0245	- 600	30.5758	2400	27.4157
-3500	33.9047	- 500	30.4659	2500	27.3151
-3400	33.7852	- 400	30.3563	2600	27.2148
-3300	33.6661	- 300	30.2471	2700	27.1148
-3200	33.5473	- 200	30.1382	2800	27.0151
-3100	33.4288	- 100	30.0295	2900	26.9158
-3000	33.3107	0	29.9213	3000	26.8167
-2900	33.1929	100	29.8133	3100	26.7179
-2800	33.0755	200	29.7056	3200	26.6193
-2700	32.9584	300	29.5983	3300	26.5211
-2600	32.8416	400	29.4913	3400	26.4232
-2500	32.7252	500	29.3846	3500	26.3256
-2400	32.6091	600	29.2782	3600	26.2283
-2300	32.4934	700	29.1721	3700	26.1312
-2200	32.3779	800	29.0663	3800	26.0345
-2100	32.2628	900	28.9608	3900	25.9380

TABLE C-I Continued

H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)
4000	25.8418	7500	22.6532	11000	19.7909
4100	25.7459	7600	22.5670	11100	19.7136
4200	25.6504	7700	22.4811	11200	19.6365
4300	25.5550	7800	22.3954	11300	19.5599
4400	25.4600	7900	22.3100	11400	19.4834
4500	25.3653	8000	22.2249	11500	19.4071
4600	25.2708	8100	22.1401	11600	19.3310
4700	25.1767	8200	22.0555	11700	19.2555
4800	25.0828	8300	21.9711	11800	19.1797
4900	24.9892	8400	21.8871	11900	19.1044
5000	24.8959	8500	21.8033	12000	19.0293
5100	24.8029	8600	21.7197	12100	18.9545
5200	24.7101	8700	21.6364	12200	18.8799
5300	24.6177	8800	21.5534	12300	18.8055
5400	24.5255	8900	21.4706	12400	18.7314
5500	24.4336	9000	21.3881	12500	18.6575
5600	24.3419	9100	21.3058	12600	18.5839
5700	24.2506	9200	21.2238	12700	18.5105
5800	24.1595	9300	21.1421	12800	18.4373
5900	24.0687	9400	21.0606	12900	18.3644
6000	23.9782	9500	20.9793	13000	18.2917
6100	23.8880	9600	20.8983	13100	18.2192
6200	23.7980	9700	20.8176	13200	18.1470
6300	23.7083	9800	20.7371	13300	18.0749
6400	23.6189	9900	20.6569	13400	18.0032
6500	23.5297	10000	20.5769	13500	17.9316
6600	23.4409	10100	20.4972	13600	17.8603
6700	23.3523	10200	20.4177	13700	17.7892
6800	23.2639	10300	20.3385	13800	17.7184
6900	23.1759	10400	20.2595	13900	17.6477
7000	23.0881	10500	20.1808	14000	17.5773
7100	23.0006	10600	20.1023	14100	17.5072
7200	22.9133	10700	20.0241	14200	17.4372
7300	22.8263	10800	19.9461	14300	17.3675
7400	22.7396	10900	19.8684	14400	17.2980

TABLE C-I Continued

H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)
14500	17.2287	18000	14.9421	21500	12.9076
14600	17.1597	18100	14.8806	21600	12.8530
14700	17.0909	18200	14.8192	21700	12.7985
14800	17.0223	18300	14.7581	21800	12.7442
14900	16.9539	18400	14.6972	21900	12.6902
15000	16.8858	18500	14.6365	22000	12.6363
15100	16.8178	18600	14.5760	22100	12.5826
15200	16.7501	18700	14.5157	22200	12.5290
15300	16.6827	18800	14.4556	22300	12.4757
15400	16.6154	18900	14.3957	22400	12.4225
15500	16.5483	19000	14.3360	22500	12.3696
15600	16.4815	19100	14.2765	22600	12.3168
15700	16.4149	19200	14.2173	22700	12.2642
15800	16.3485	19300	14.1582	22800	12.2117
15900	16.2824	19400	14.0993	22900	12.1595
16000	16.2164	19500	14.0406	23000	12.1074
16100	16.1507	19600	13.9821	23100	12.0556
16200	16.0851	19700	13.9238	23200	12.0039
16300	16.0198	19800	13.8657	23300	11.9523
16400	15.9547	19900	13.8078	23400	11.9010
16500	15.8899	20000	13.7501	23500	11.8498
16600	15.8252	20100	13.6926	23600	11.7988
16700	15.7608	20200	13.6352	23700	11.7480
16800	15.6965	20300	13.5781	23800	11.6974
16900	15.6325	20400	13.5212	23900	11.6469
17000	15.5687	20500	13.4644	24000	11.5967
17100	15.5051	20600	13.4079	24100	11.5466
17200	15.4417	20700	13.3516	24200	11.4966
17300	15.3785	20800	13.2954	24300	11.4469
17400	15.3155	20900	13.2394	24400	11.3973
17500	15.2528	21000	13.1836	24500	11.3479
17600	15.1902	21100	13.1281	24600	11.2987
17700	15.1279	21200	13.0727	24700	11.2496
17800	15.0657	21300	13.0175	24800	11.2007
17900	15.0038	21400	12.9624	24900	11.1520

TABLE C-I Continued

H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)
25000	11.1035	28500	9.50923	32000	8.10561
25100	11.0551	28600	9.46658	32100	8.06813
25200	11.0069	28700	9.42407	32200	8.03079
25300	10.9589	28800	9.38172	32300	7.99358
25400	10.9110	28900	9.33952	32400	7.95652
25500	10.8634	29000	9.29748	32500	7.91960
25600	10.8158	29100	9.25559	32600	7.88281
25700	10.7685	29200	9.21385	32700	7.84616
25800	10.7213	29300	9.17227	32800	7.80966
25900	10.6743	29400	9.13083	32900	7.77328
26000	10.6274	29500	9.08956	33000	7.73705
26100	10.5808	29600	9.04843	33100	7.70095
26200	10.5342	29700	9.00745	33200	7.66499
26300	10.4879	29800	8.96662	33300	7.62917
26400	10.4417	29900	8.92594	33400	7.59348
26500	10.3957	30000	8.88541	33500	7.55793
26600	10.3498	30100	8.84503	33600	7.52251
26700	10.3041	30200	8.80480	33700	7.48722
26800	10.2586	30300	8.76472	33800	7.45208
26900	10.2133	30400	8.72479	33900	7.41706
27000	10.16[illegible]1	30500	8.68500	34000	7.38218
27100	10.1230	30600	8.64536	34100	7.34743
27200	10.0781	30700	8.60587	34200	7.31281
27300	10.0334	30800	8.56652	34300	7.27833
27400	9.98887	30900	8.52732	34400	7.24397
27500	9.94447	31000	8.48826	34500	7.20975
27600	9.90023	31100	8.44935	34600	7.17566
27700	9.85616	31200	8.41059	34700	7.14170
27800	9.81224	31300	8.37197	34800	7.10787
27900	9.76848	31400	8.33349	34900	7.07417
28000	9.72488	31500	8.29515	35000	7.04060
28100	9.68144	31600	8.25696	35100	7.00716
28200	9.63815	31700	8.21891	35200	6.97385
28300	9.59502	31800	8.18100	35300	6.94066
28400	9.55205	31900	8.14324	35400	6.90761

TABLE C-I Continued

H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)
35500	6.87468	42000	5.03045	49000	3.59328
35600	6.84188	42200	4.98232	49200	3.55890
35700	6.80920	42400	4.93466	49400	3.52486
35800	6.77665	42600	4.88745	49600	3.49113
35900	6.74423	42800	4.84069	49800	3.45774
36000	6.71194	43000	4.79439	50000	3.42466
36200	6.64774	43200	4.74852	50200	3.39189
36400	6.58414	43400	4.70309	50400	3.35945
36600	6.52115	43600	4.65810	50600	3.32731
36800	6.45877	43800	4.61354	50800	3.29548
37000	6.39698	44000	4.56940	51000	3.26395
37200	6.33578	44200	4.52569	51200	3.23273
37400	6.27517	44400	4.48239	51400	3.20180
37600	6.21514	44600	4.43951	51600	3.17117
37800	6.15568	44800	4.39704	51800	3.14083
38000	6.09679	45000	4.35497	52000	3.11078
38200	6.03846	45200	4.31331	52200	3.08103
38400	5.98070	45400	4.27205	52400	3.05155
38600	5.92348	45600	4.23118	52600	3.02236
38800	5.86681	45800	4.19070	52800	2.99344
39000	5.81069	46000	4.15061	53000	2.96481
39200	5.75510	46200	4.11090	53200	2.93644
39400	5.70004	46400	4.07157	53400	2.90835
39600	5.64551	46600	4.03262	53600	2.88053
39800	5.59151	46800	3.99405	53800	2.85297
40000	5.53801	47000	3.95504	54000	2.82568
40200	5.48503	47200	3.91799	54200	2.79864
40400	5.43256	47400	3.88051	54400	2.77187
40600	5.38059	47600	3.84339	54600	2.74535
40800	5.32911	47800	3.80662	54800	2.71909
41000	5.27813	48000	3.77020	55000	2.69308
41200	5.22764	48200	3.73413	55200	2.66731
41400	5.17763	48400	3.69841	55400	2.64180
41600	5.12809	48600	3.66303	55600	2.61652
41800	5.07904	48800	3.62799	55800	2.59149

TABLE C-I Concluded

H_m (ft)	P_m(in. Hg)	H_m (ft)	P_m(in. Hg)
56000	2.56670	63000	1.83341
56200	2.54215	63200	1.81587
56400	2.51733	63400	1.79850
56600	2.49374	63600	1.78129
56800	2.46988	63800	1.76425
57000	2.44625	64000	1.74737
57200	2.42285	64200	1.73066
57400	2.39967	64400	1.71410
57600	2.37672	64600	1.69770
57800	2.35398	64800	1.68146
58000	2.33146	65000	1.66538
58200	2.30916	65200	1.64944
58400	2.28706	65400	1.63366
58600	2.26519	65600	1.61804
58800	2.24351	65800	1.60256
59000	2.22205		
59200	2.20079		
59400	2.17974		
59600	2.15889		
59800	2.13823		
60000	2.11778		
60200	2.09752		
60400	2.07745		
60600	2.05758		
60800	2.03789		
61000	2.01840		
61200	1.99909		
61400	1.97996		
61600	1.96102		
61800	1.94226		
62000	1.92368		
62200	1.90528		
62400	1.88705		
62600	1.86900		
62800	1.85112		

TABLE C-II

THE RATIO OF MEASURED PITOT PRESSURE ($P_{t'm}$) TO MEASURED STATIC PRESSURE (P_m) AS A FUNCTION OF MEASURED MACH NUMBER (M_m)

M_m	$P_{t'm}/P_m$	M_m	$P_{t'm}/P_m$	M_m	$P_{t'm}/P_m$
0	1.000000	.30	1.06443	.60	1.2755
.01	1.000070	.31	1.06890	.61	1.2856
.02	1.000280	.32	1.07353	.62	1.2959
.03	1.000631	.33	1.07833	.63	1.3065
.04	1.001124	.34	1.08329	.64	1.3173
.05	1.001751	.35	1.08841	.65	1.3283
.06	1.002522	.36	1.09370	.66	1.3396
.07	1.003434	.37	1.09916	.67	1.3511
.08	1.004487	.38	1.10478	.68	1.3628
.09	1.005682	.39	1.11058	.69	1.3749
.10	1.007018	.40	1.1166	.70	1.3871
.11	1.008496	.41	1.1227	.71	1.3996
.12	1.010116	.42	1.1290	.72	1.4124
.13	1.011880	.43	1.1355	.73	1.4254
.14	1.013787	.44	1.1422	.74	1.4387
.15	1.01584	.45	1.1491	.75	1.4523
.16	1.01804	.46	1.156[illegible]	.76	1.4661
.17	1.02038	.47	1.1[illegible]	.77	1.4803
.18	1.02286	.48	1.1708	.78	1.4947
.19	1.02550	.49	1.1784	.79	1.5094
.20	1.02828	.50	1.1862	.80	1.5243
.21	1.03121	.51	1.1942	.81	1.5396
.22	1.03429	.52	1.2024	.82	1.5552
.23	1.03752	.53	1.2108	.83	1.5711
.24	1.04090	.54	1.2194	.84	1.5873
.25	1.04444	.55	1.2283	.85	1.6038
.26	1.04813	.56	1.2373	.86	1.6207
.27	1.05197	.57	1.2465	.87	1.6378
.28	1.05596	.58	1.2560	.88	1.6553
.29	1.06012	.59	1.2656	.89	1.6731

TABLE C-II Concluded

M_m	$P_{t'm}/P_m$	M_m	$P_{t'm}/P_m$	M_m	$P_{t'm}/P_m$
.90	1.6913	.95	1.7874	1.00	1.8929
.91	1.7098	.96	1.8078		
.92	1.7287	.97	1.8285		
.93	1.7479	.98	1.8496		
.94	1.7675	.99	1.8711		

TABLE C-III

ABBREVIATED STANDARD ATMOSPHERE TABLES
(From References 6 and 13)

Geopotential Altitude H (ft)	P ("Hg)	T (°R)	$\sigma = (\rho/\rho_{sl})$
-5000	35.7382	536.519	1.1547
-4000	34.5072	532.953	1.1224
-3000	33.3107	529.386	1.0908
-2000	32.1481	525.820	1.0598
-1000	31.0185	522.254	1.0296
0	29.9213	518.688	1.0000
1000	28.8557	515.122	.97106
2000	27.8210	511.556	.94277
3000	26.8167	507.990	.91512
4000	25.8418	504.423	.88808
5000	24.8959	500.857	.86167
6000	23.9782	497.291	.83586
7000	23.0881	493.725	.81064
8000	22.2249	490.159	.78601
9000	21.3881	486.593	.76196
10000	20.5769	483.026	.73848
11000	19.7909	479.460	.71555
12000	19.0293	475.894	.69317
13000	18.2917	472.328	.67133
14000	17.5773	468.762	.65002
15000	16.8858	465.196	.62923
16000	16.2164	461.629	.60896
17000	15.5687	458.063	.58919
18000	14.9421	454.497	.56991
19000	14.3360	450.931	.55112
20000	13.7501	447.365	.53281
21000	13.1836	443.799	.51496
22000	12.6363	440.232	.49758
23000	12.1074	436.666	.48065
24000	11.5967	433.100	.46416
25000	11.1035	429.534	.44811

TABLE C-III Continued

Geopotential Altitude H (ft)	P ("Hg)	T (°R)	$\sigma = (\rho/\rho_{sl})$
26000	10.6274	425.968	.43249
27000	10.1681	422.402	.41729
28000	9.72488	418.836	.40250
29000	9.29748	415.269	.38812
30000	8.88541	411.703	.37413
31000	8.48826	408.137	.36053
32000	8.10561	404.571	.34731
33000	7.73705	401.005	.33447
34000	7.38218	397.439	.32199
35000	7.04060	393.872	.30987
36000	6.71194	390.306	.29810
37000	6.39698	389.988	.28435
38000	6.09679	389.988	.27100
39000	5.81069	389.988	.25829
40000	5.53801	389.988	.24617
41000	5.27813	389.988	.23461
42000	5.03045	389.988	.22361
43000	4.79439	389.988	.21311
44000	4.56940	389.988	.20311
45000	4.35497	389.988	.19358
46000	4.15061	389.988	.18450
47000	3.95584	389.988	.17584
48000	3.77020	389.988	.16759
49000	3.59328	389.988	.15972
50000	3.42466	389.988	.15223
51000	3.26395	389.988	.14508
52000	3.11078	389.988	.13828
53000	2.96481	389.988	.13179
54000	2.82568	389.988	.12560
55000	2.69308	389.988	.11971

TABLE C-III Concluded

Geopotential Altitude H (ft)	P ("Hg)	T (°R)	$\sigma = (\rho/\rho_{s1})$
56000	2.56670	389.988	.11409
57000	2.44625	389.988	.10874
58000	2.33146	389.988	.10363
59000	2.22205	389.988	.098771
60000	2.11778	389.988	.094136
61000	2.01840	389.988	.089718
62000	1.92368	389.988	.085508
63000	1.83341	389.988	.081496
64000	1.74737	389.988	.077671
65000	1.66538	389.988	.074026
66000	1.58723	390.180	.070516
67000	1.51284	390.729	.067116
68000	1.44203	391.278	.063885
69000	1.37463	391.826	.060814
70000	1.31046	392.375	.057894
71000	1.24938	392.923	.055118
72000	1.19122	393.472	.052479
73000	1.13584	394.021	.049970
74000	1.08311	394.569	.047584
75000	1.03290	395.118	.045315
76000	0.985074	395.667	.043157
77000	0.939529	396.215	.041105
78000	0.896148	396.764	.039152
79000	0.854826	397.313	.037296
80000	0.815462	397.861	.035529

Appendix D

Data Reduction Charts

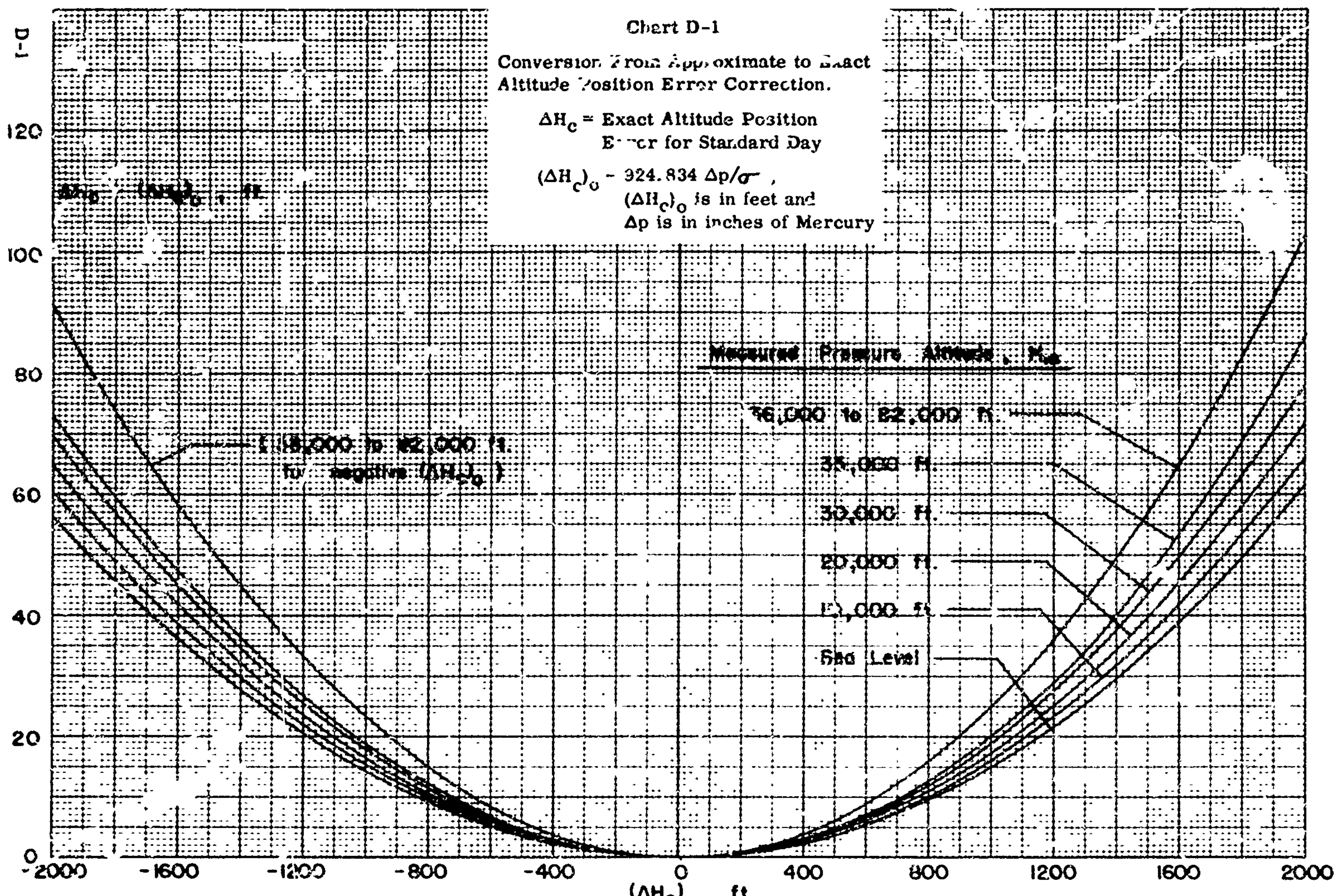


Chart D-1

Conversion From Approximate to Exact Altitude Position Error Correction.

ΔH_c = Exact Altitude Position Error for Standard Day

$(\Delta H_c)_o$ = 924.834 $\Delta p/\sigma$,
$(\Delta H_c)_o$ is in feet and
Δp is in inches of Mercury

Chart D-2

Variation of Static Pressure With Pressure Altitude From a Base Condition of Known Pressure (p_B) or Known Pressure Altitude (H_B) and Known Absolute Static Temperature (T_B)

1. <u>For $0 \leq H \leq 36,089$ ft. in the Standard Atmosphere:</u>

   Temperature Lapse Rate = L = -6.5°K/km = -0.00356616 °R/ft.

$$\frac{p - p_B}{p_B} = -1.0 + \left[1.0 - 0.00356616 \frac{°R}{ft.} \left(\frac{H - H_B}{T_B} \right) \right]^{5.2561}$$

2. <u>For 36,089 ft. $< H < 82,021$ ft. in the Standard Atmosphere:</u>

   Temperature Lapse Rate = L = 0

$$\frac{p - p_B}{p_B} = -1.0 + e^{-0.018744 \frac{°R}{ft.} (H - H_B) / T_B}$$

3. <u>For Non-Standard Lapse Rate, $L \neq 0$ (°R/ft.):</u>

$$\frac{p - p_B}{p_B} = -1.0 + \left[1.0 + L \left(\frac{H - H_B}{T_B} \right) \right]^{-0.01844 / L}$$

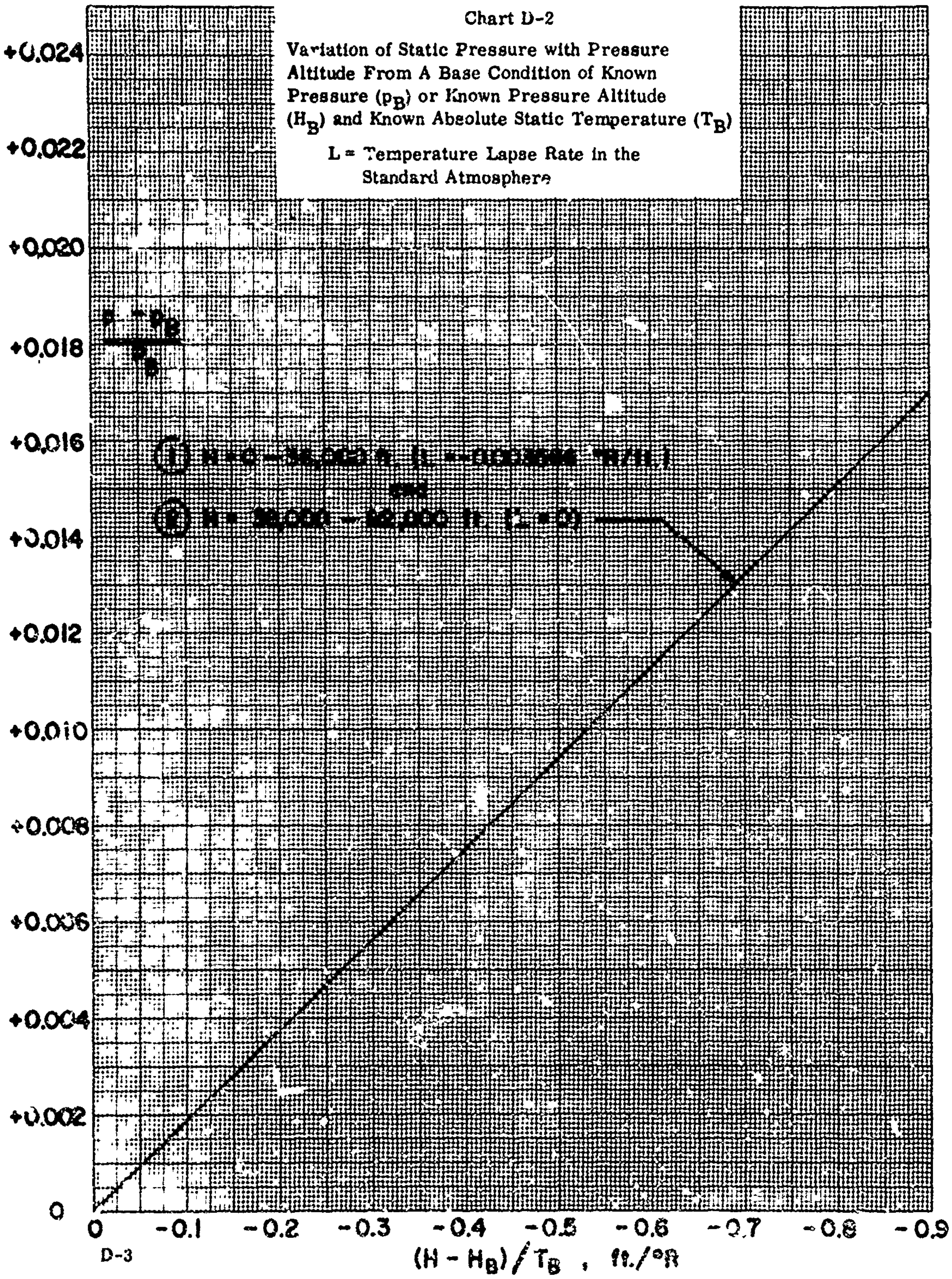


Chart D-2

Variation of Static Pressure with Pressure Altitude From A Base Condition of Known Pressure (p_B) or Known Pressure Altitude (H_B) and Known Absolute Static Temperature (T_B)

L = Temperature Lapse Rate in the Standard Atmosphere

Chart D-2, Continued

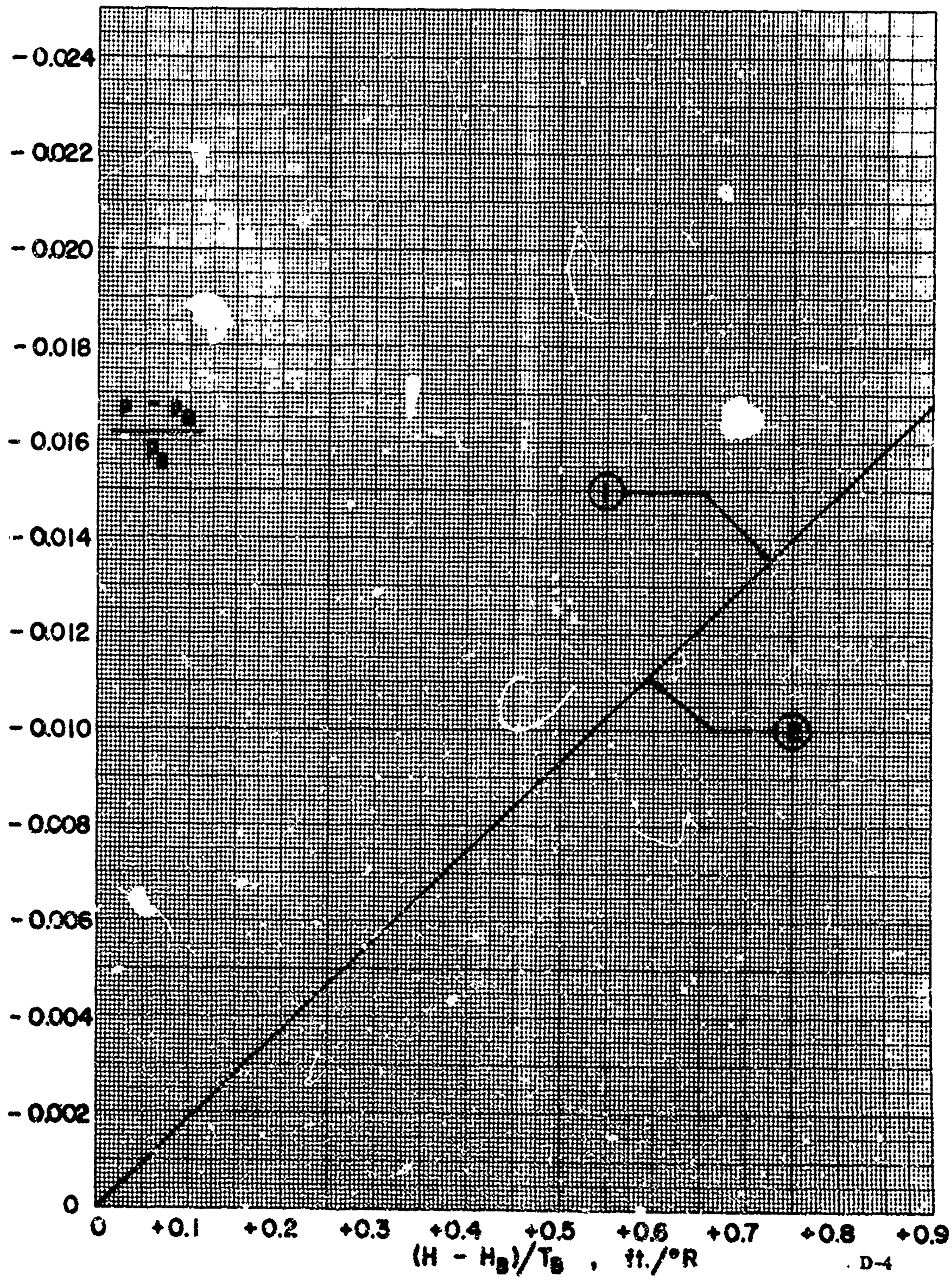


Chart D-2, Continued

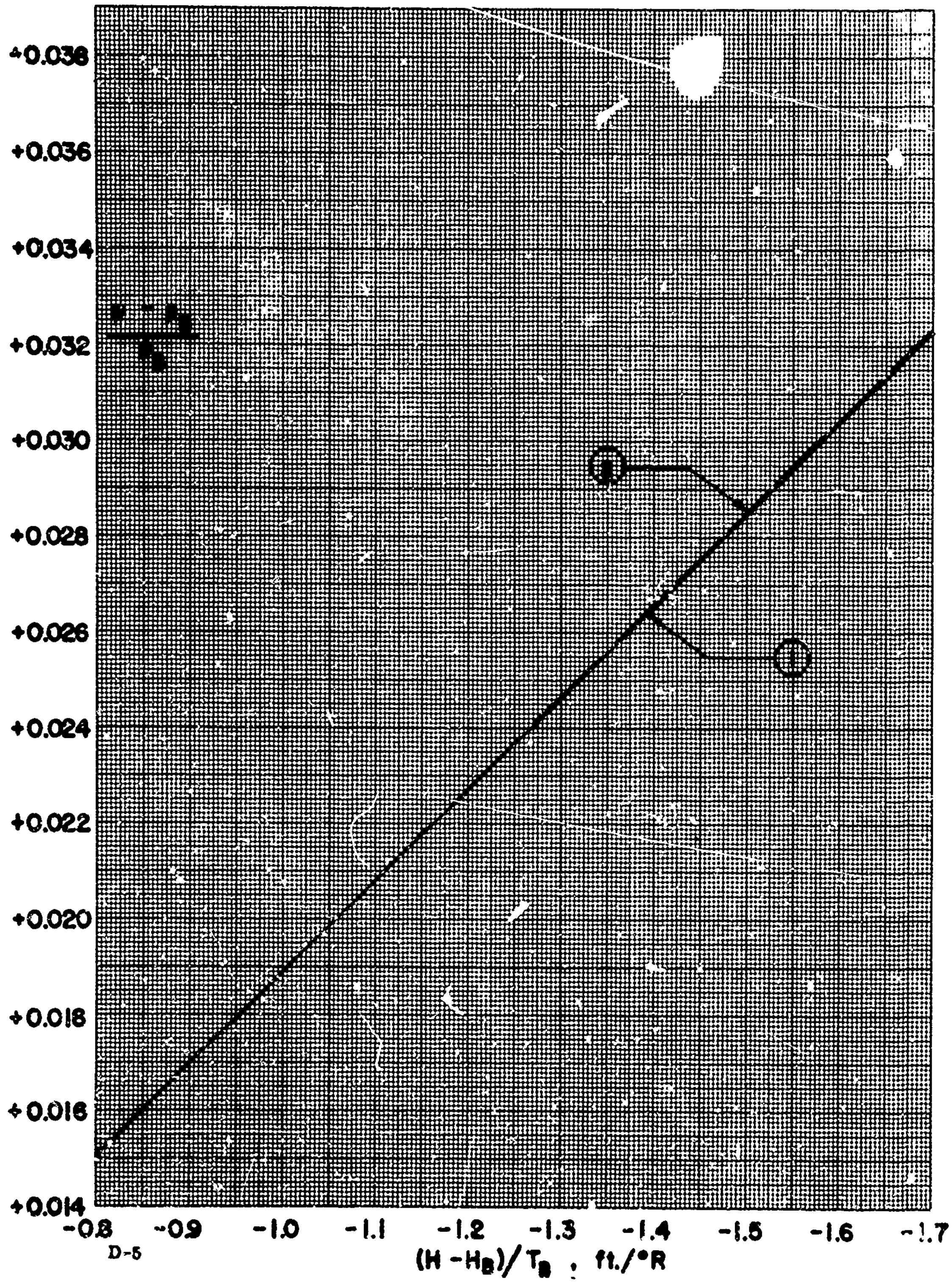


Chart D-2, Continued

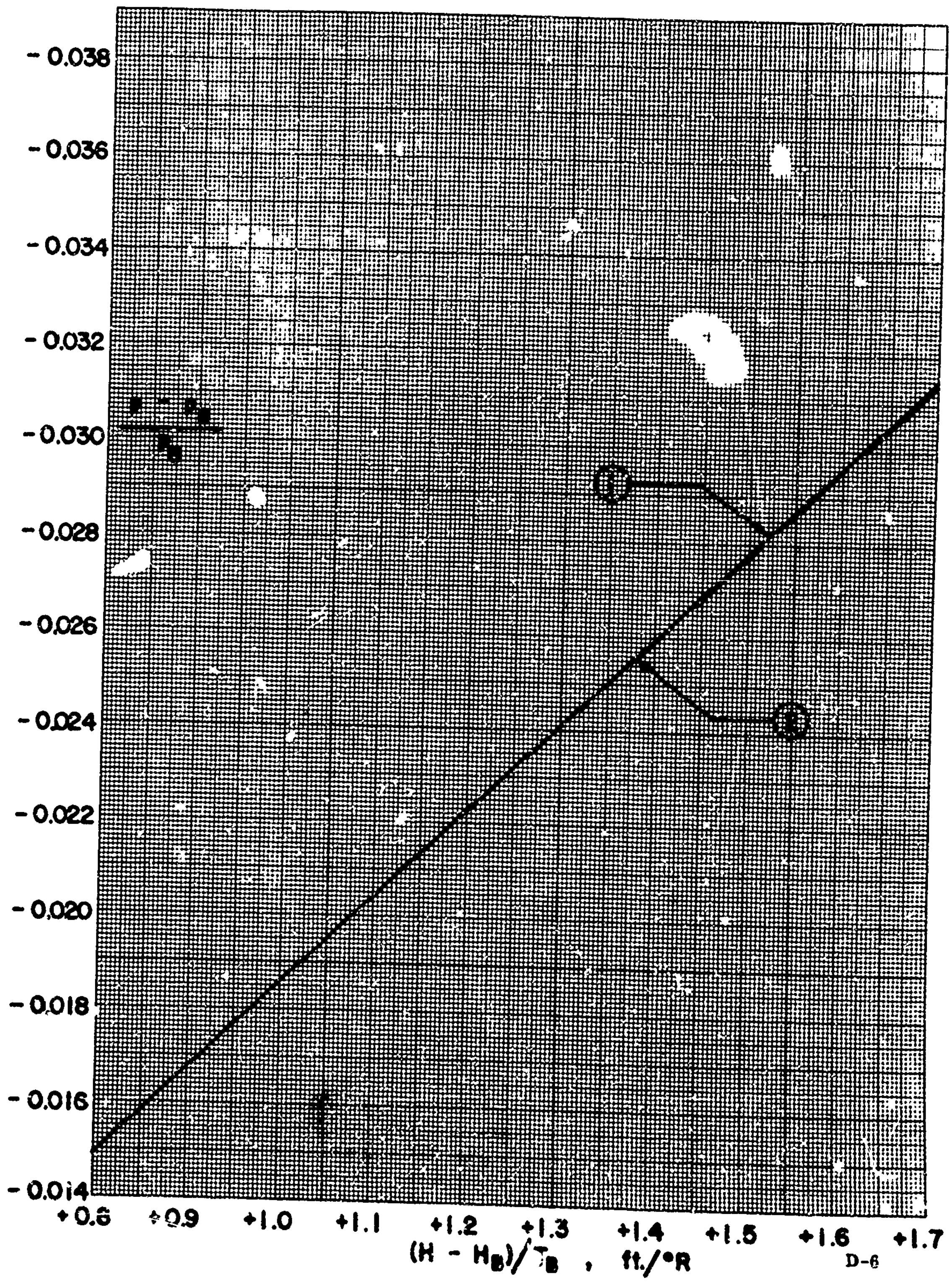


Chart D-2, Continued

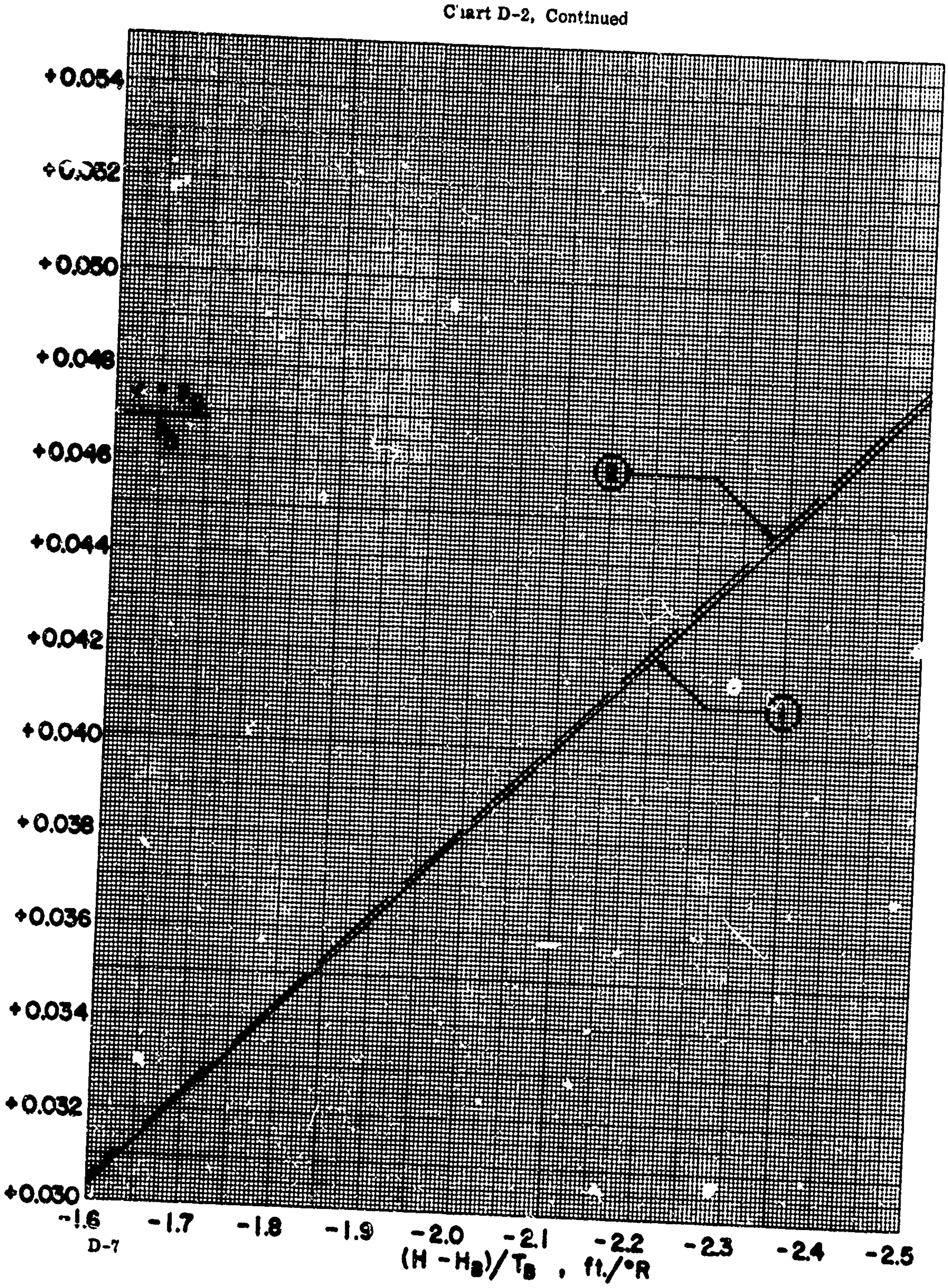


Chart D-2, Continued

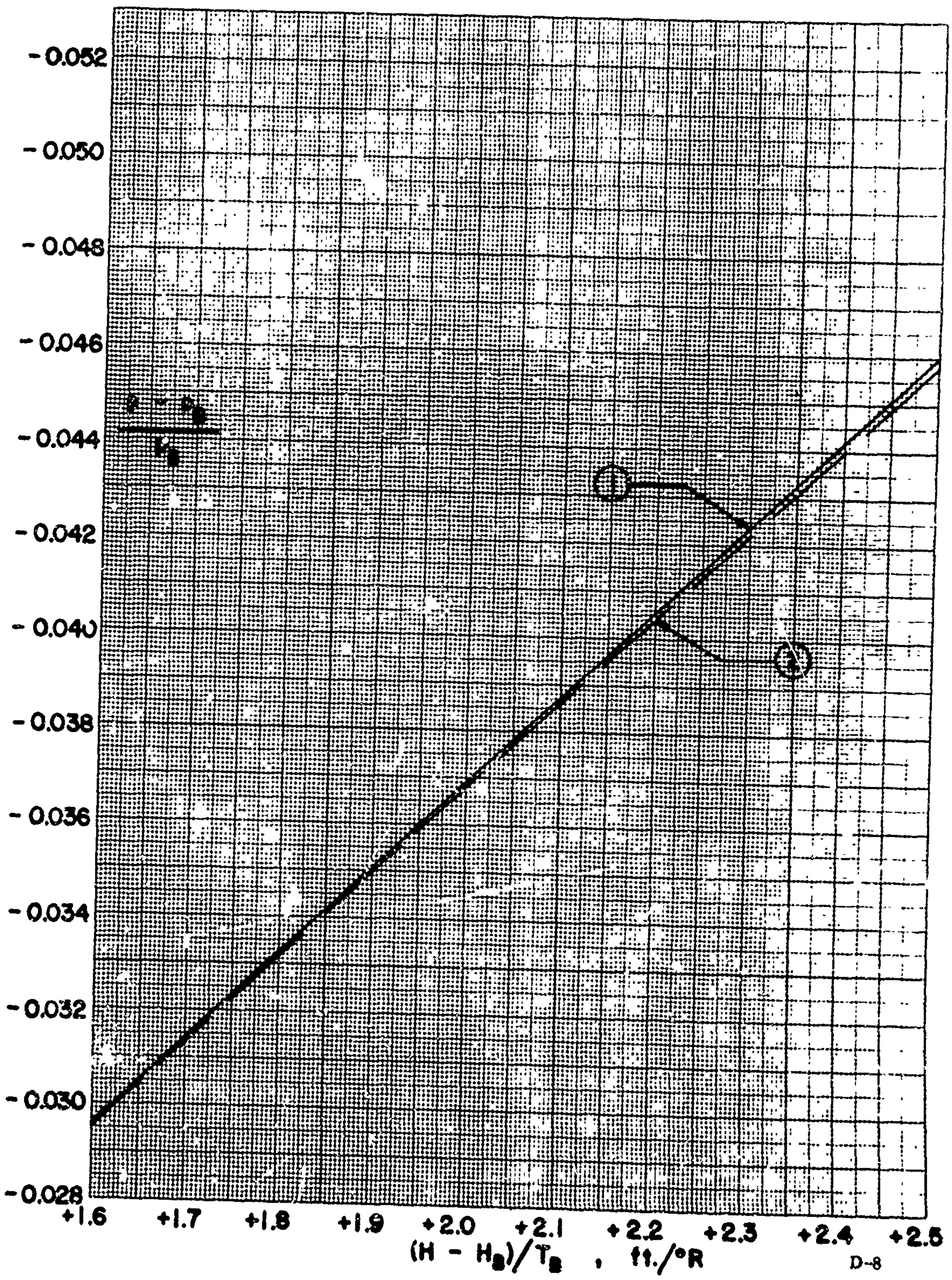


Chart D-2, Continued

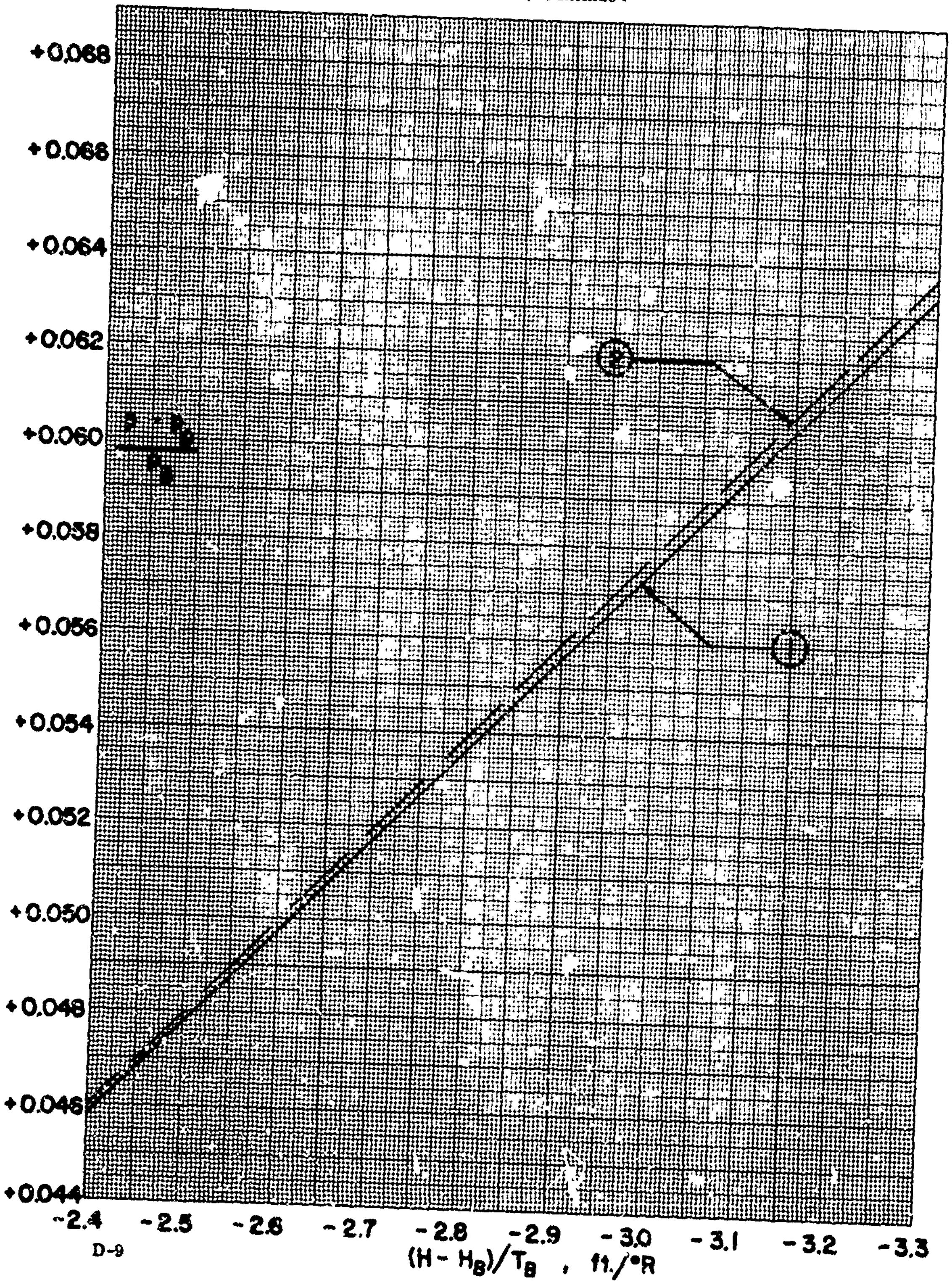


Chart D-2, Continued

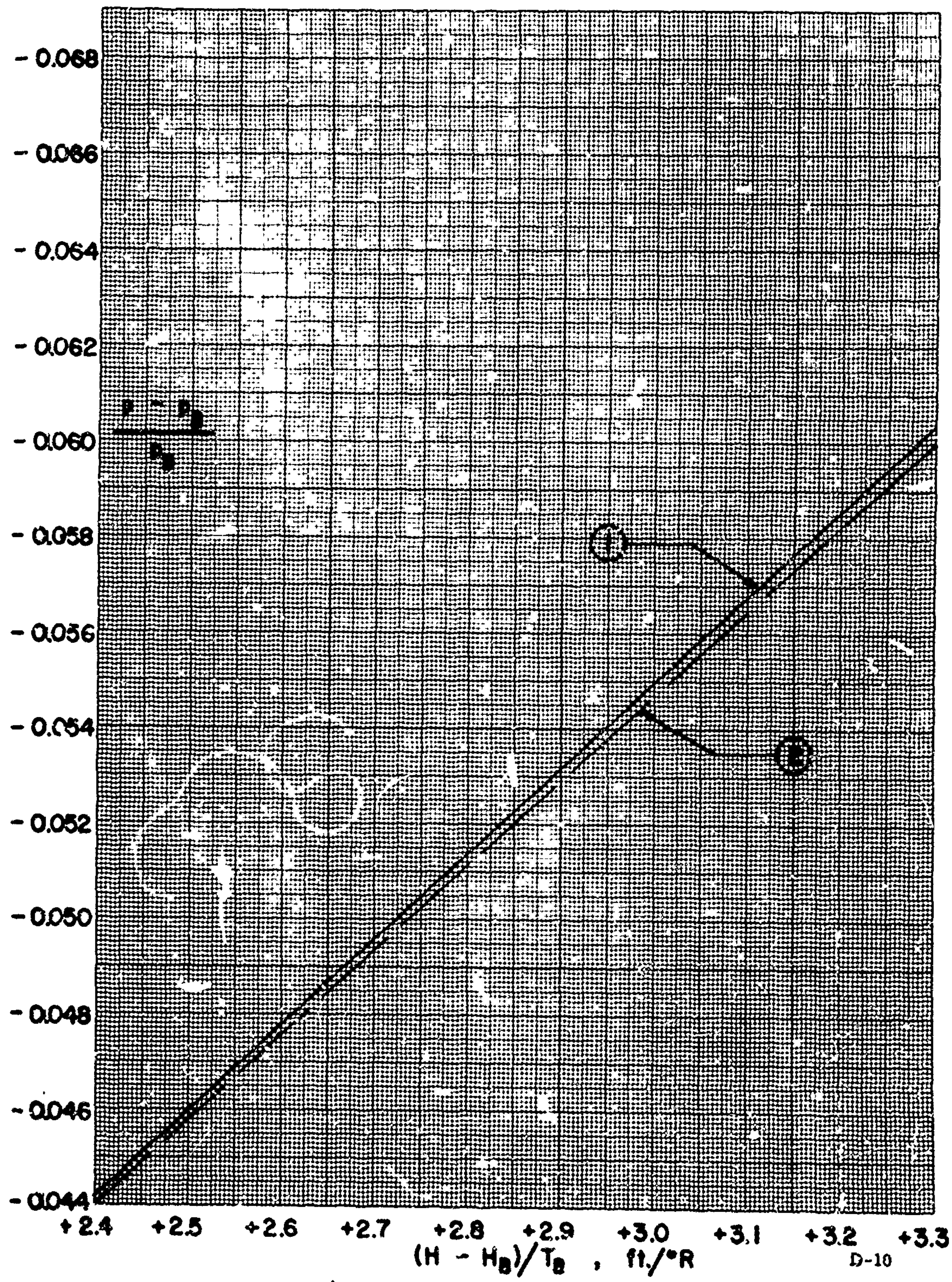


Chart D-2, Continued

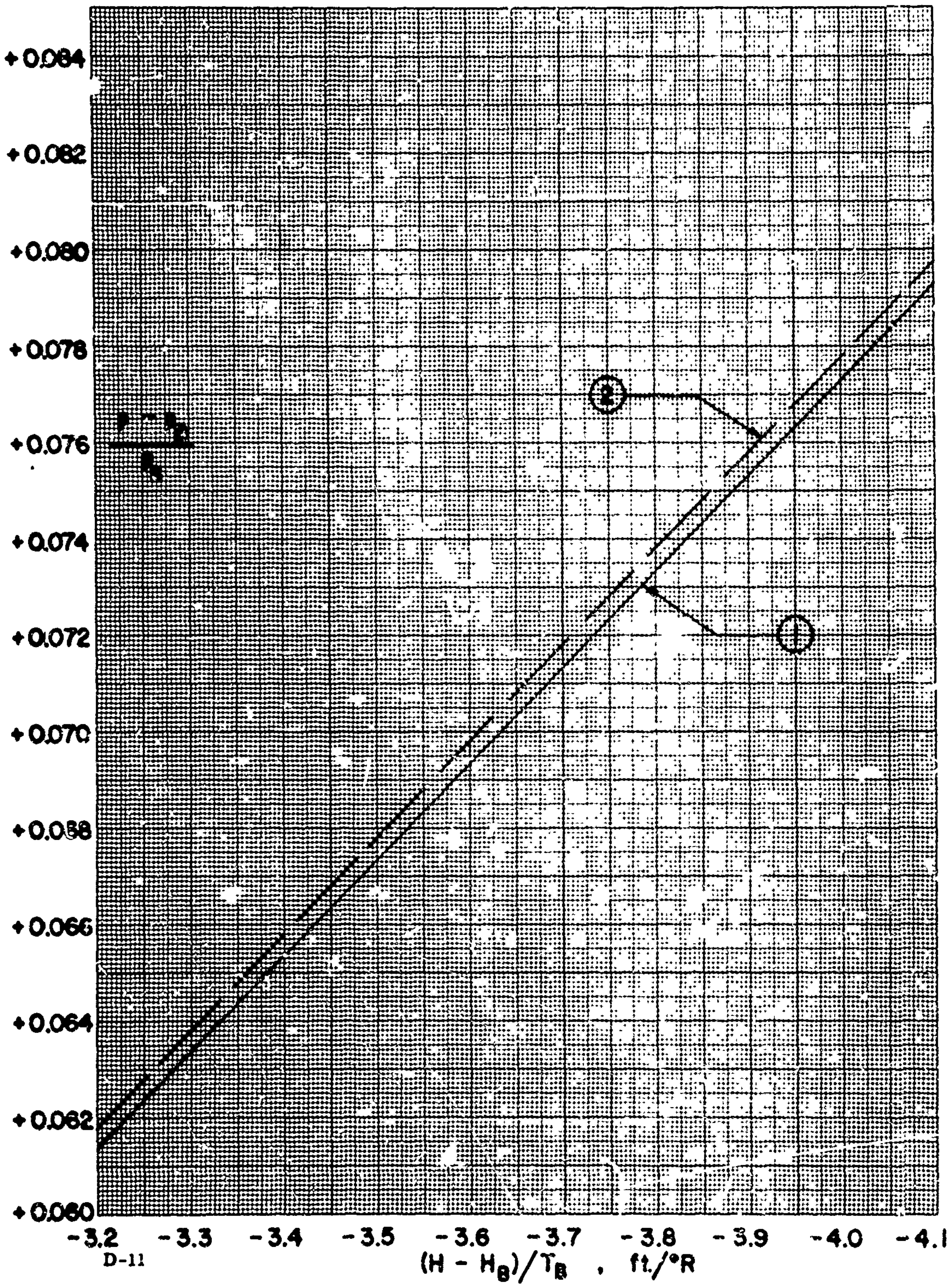
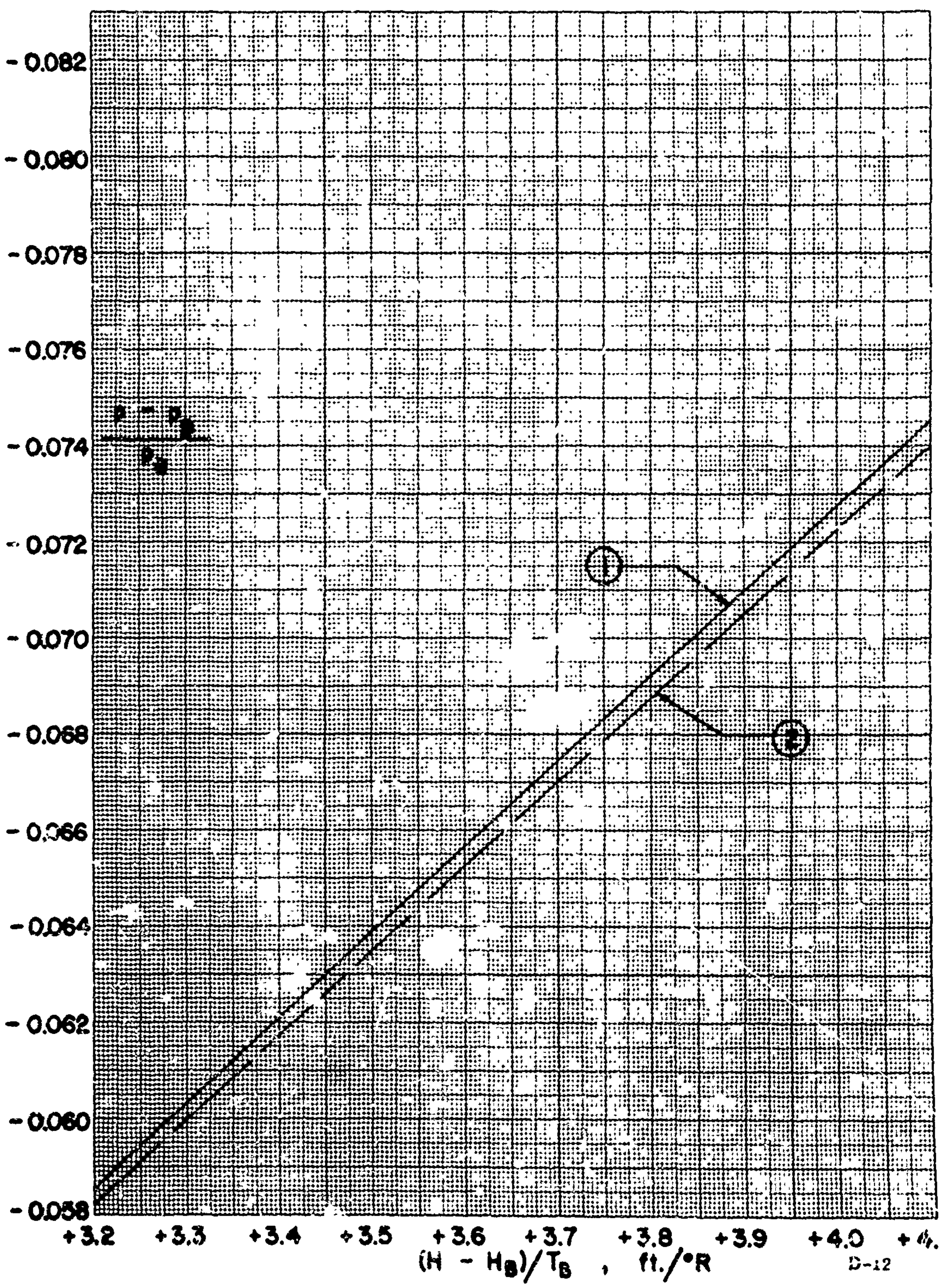
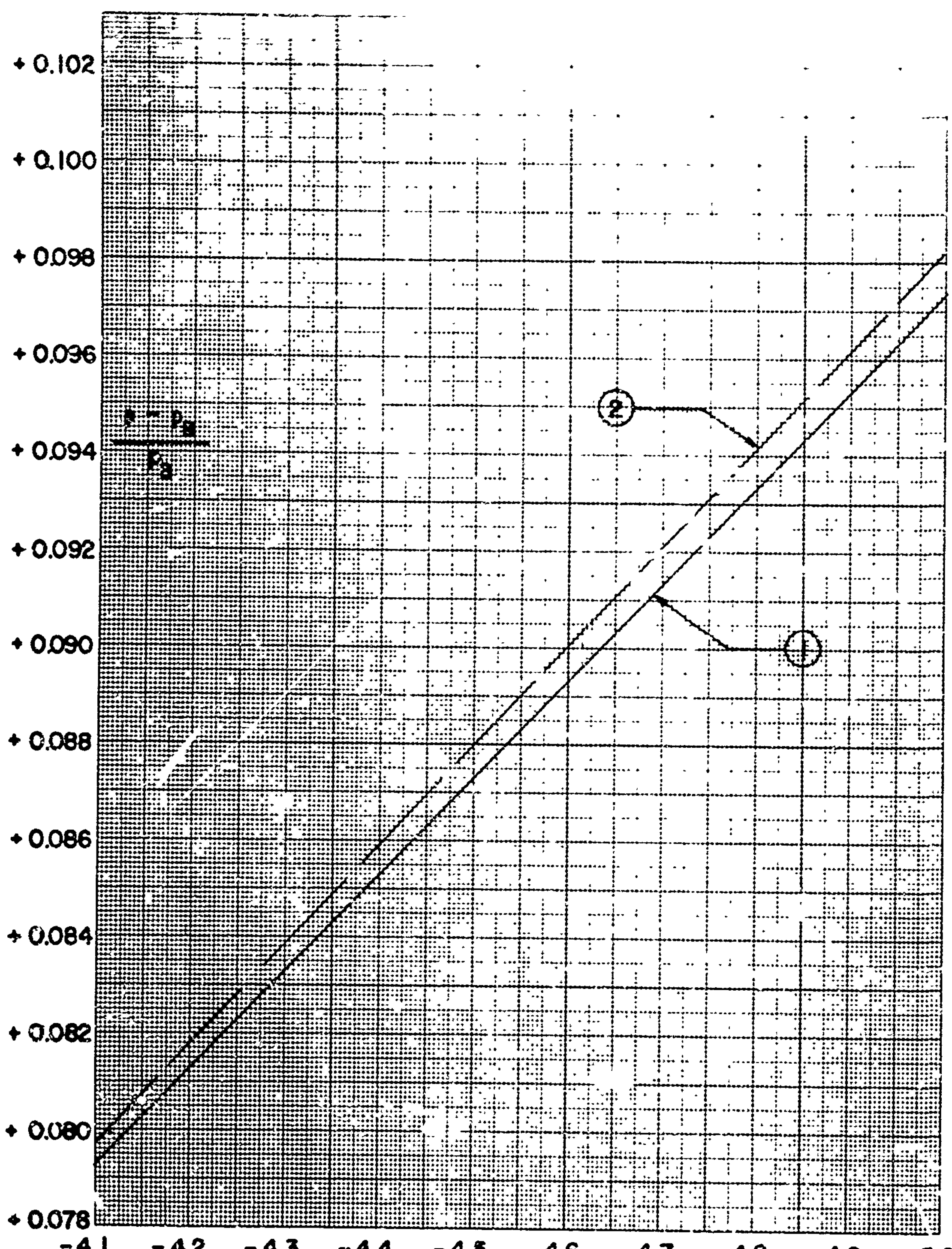
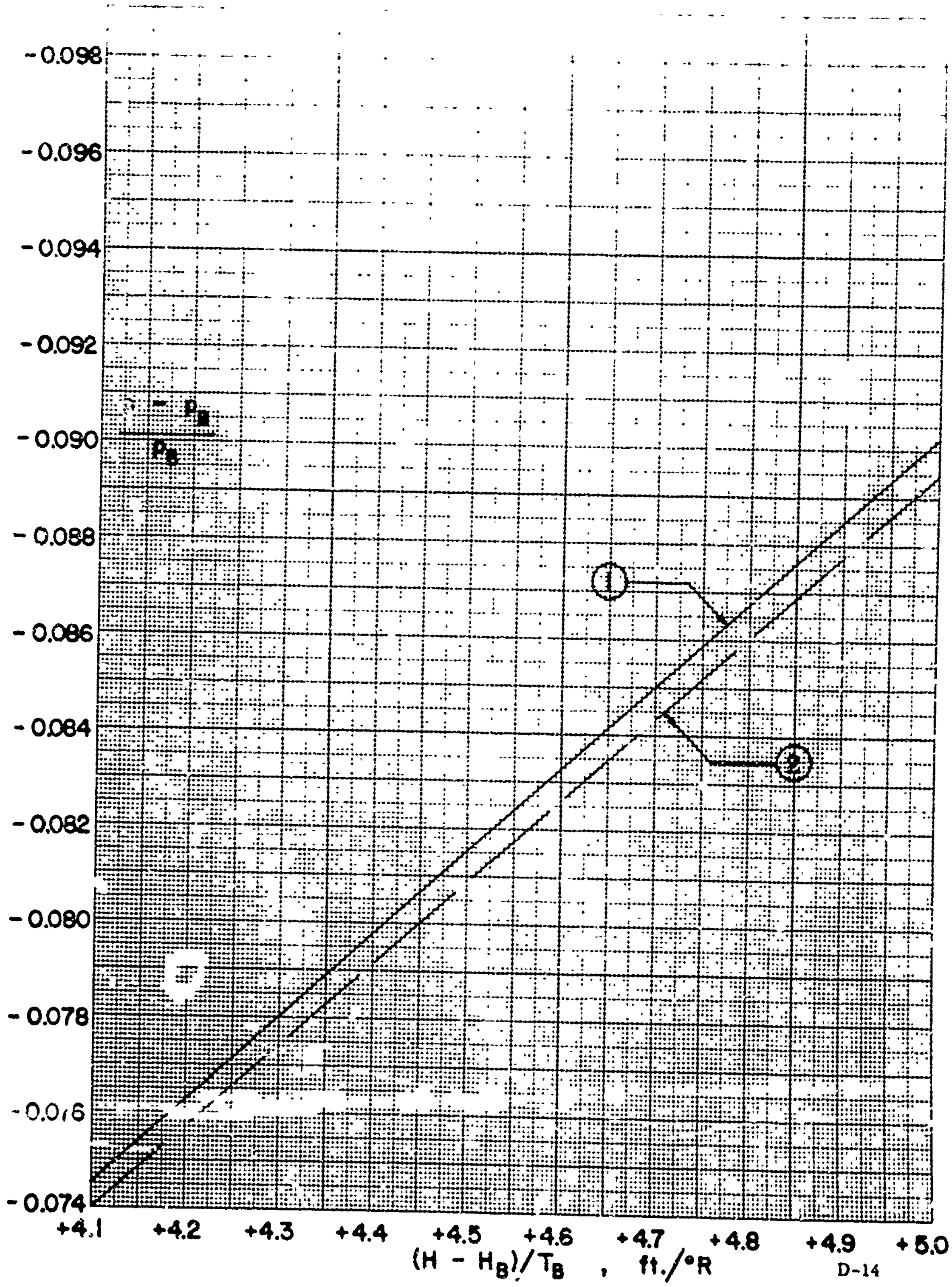


Chart D-2, Continued

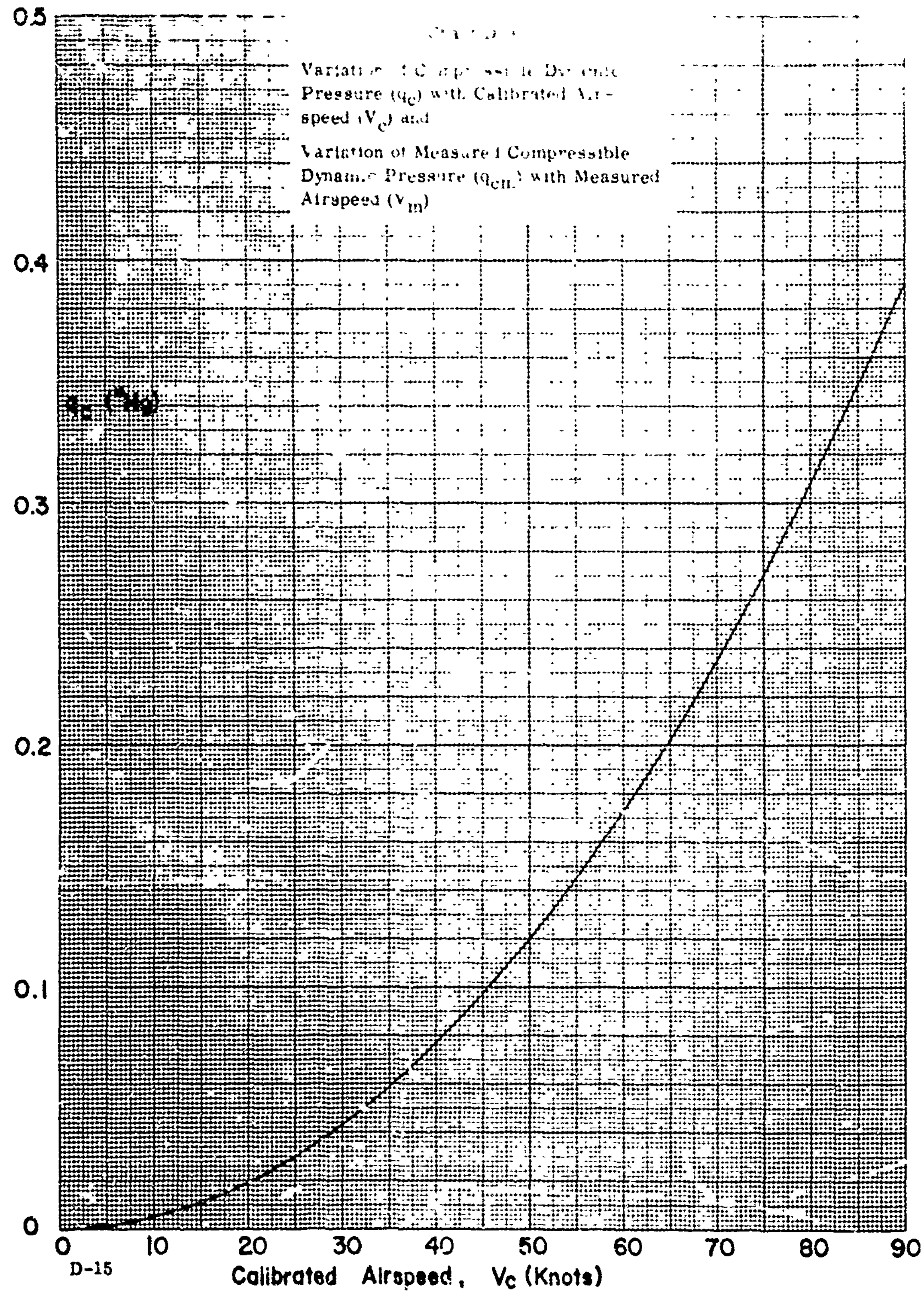




+ 0.102
+ 0.100
+ 0.098
+ 0.096
+ 0.094
+ 0.092
+ 0.090
+ 0.088
+ 0.086
+ 0.084
+ 0.082
+ 0.080
+ 0.078
$\frac{P - P_B}{P_B}$
2
1
-4.1 -4.2 -4.3 -4.4 -4.5 -4.6 -4.7 -4.8 -4.9 -5.0
$(H - H_B)/T_B$, ft./°R



-0.098
-0.096
-0.094
-0.092
-0.090
-0.088
-0.086
-0.084
-0.082
-0.080
-0.078
-0.076
-0.074
$\frac{p - p_B}{p_B}$
1
2
+4.1
+4.2
+4.3
+4.4
+4.5
+4.6
+4.7
+4.8
+4.9
+5.0
$(H - H_B)/T_B$, ft./°R


Variation of Compressible Dynamic
Pressure (q_c) with Calibrated Air-
speed (V_c) and
Variation of Measured Compressible
Dynamic Pressure (q_{cm}) with Measured
Airspeed (V_m)
q_c ("Hg)
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
Calibrated Airspeed, V_c (Knots)

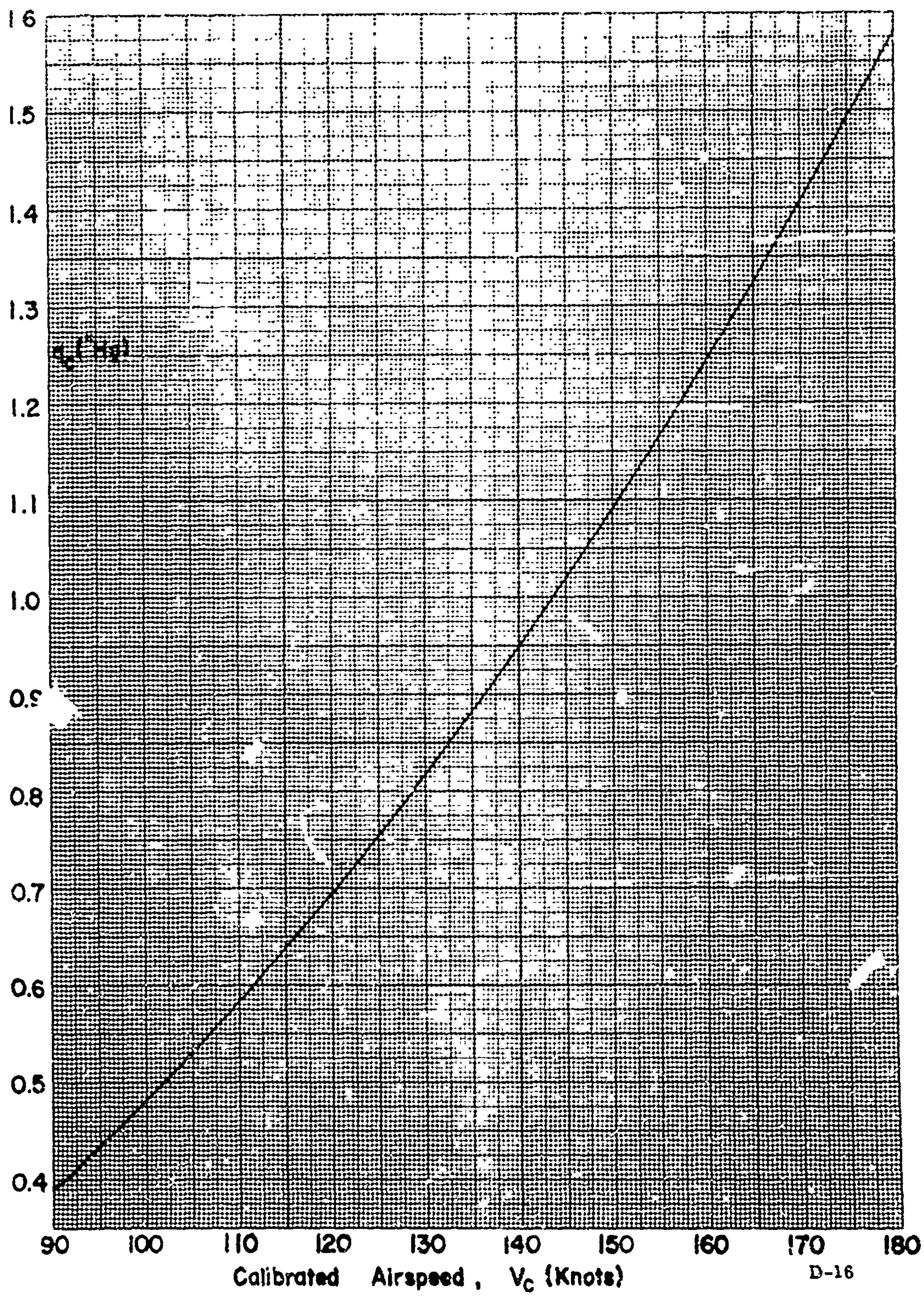

1.6
1.5
1.4
1.3
q_c ("Hg)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
90
100
110
120
130
140
150
160
170
180
Calibrated Airspeed, V_c (Knots)

Chart D : Continued

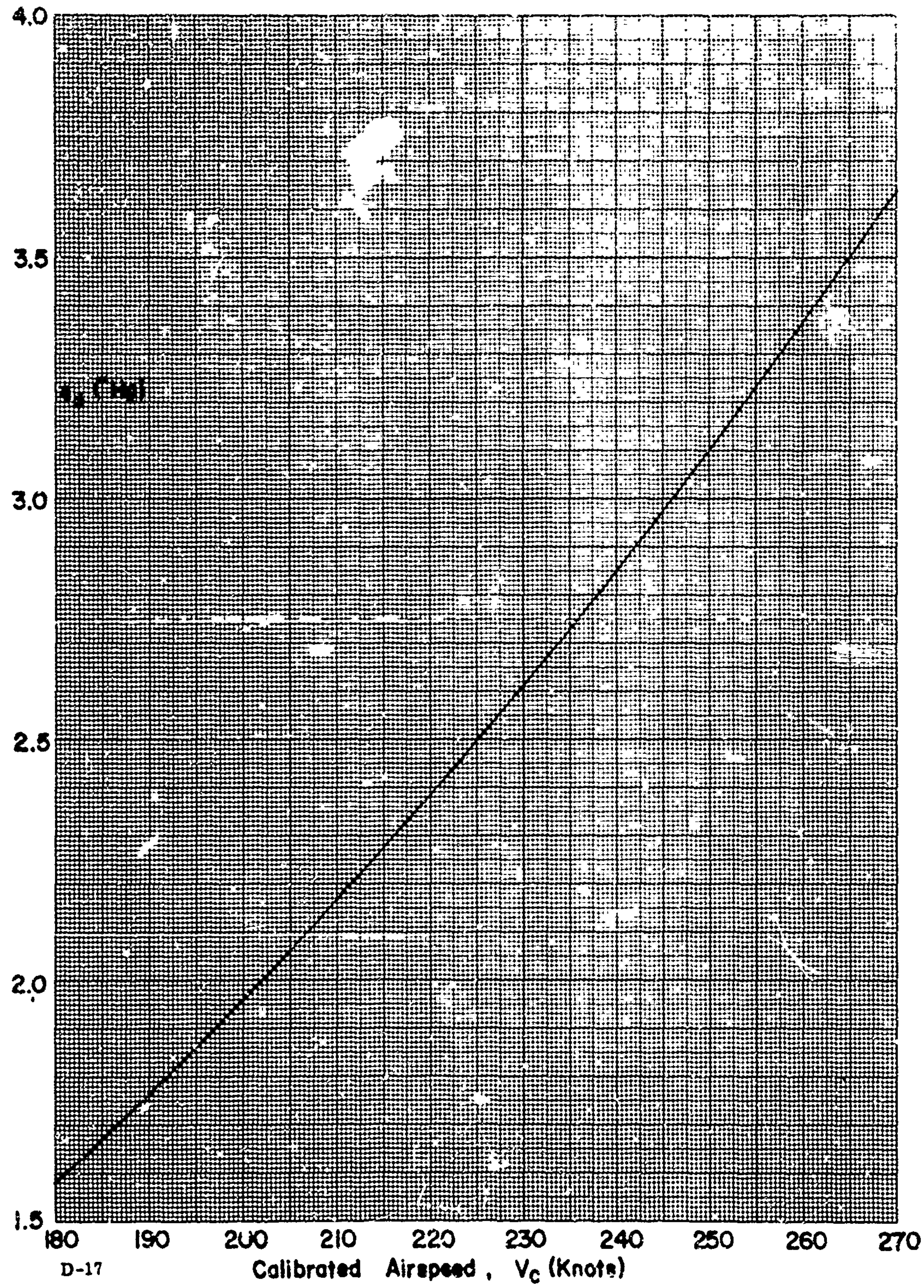


Chart D-3. Continued

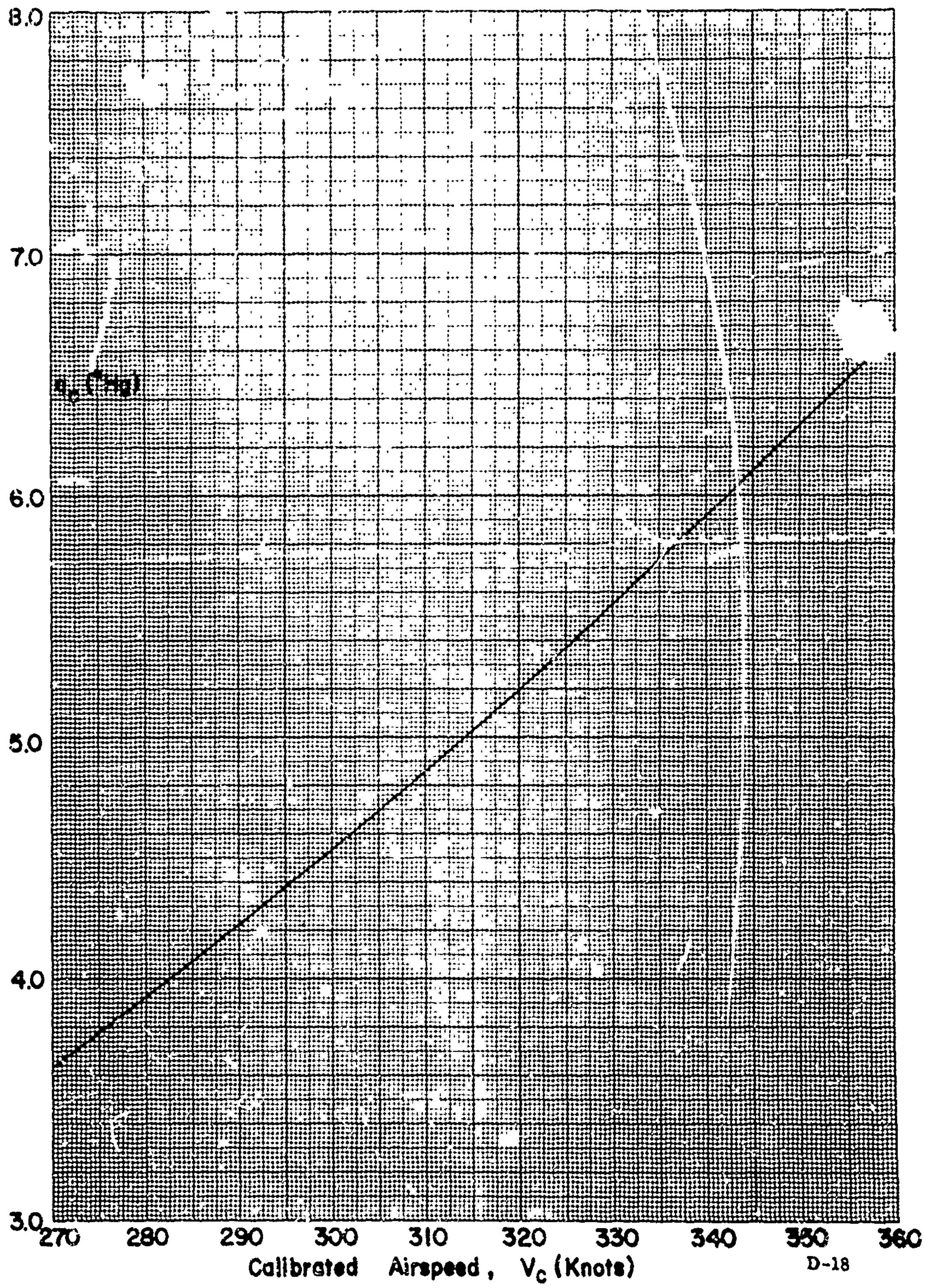


Chart D-3 Continued

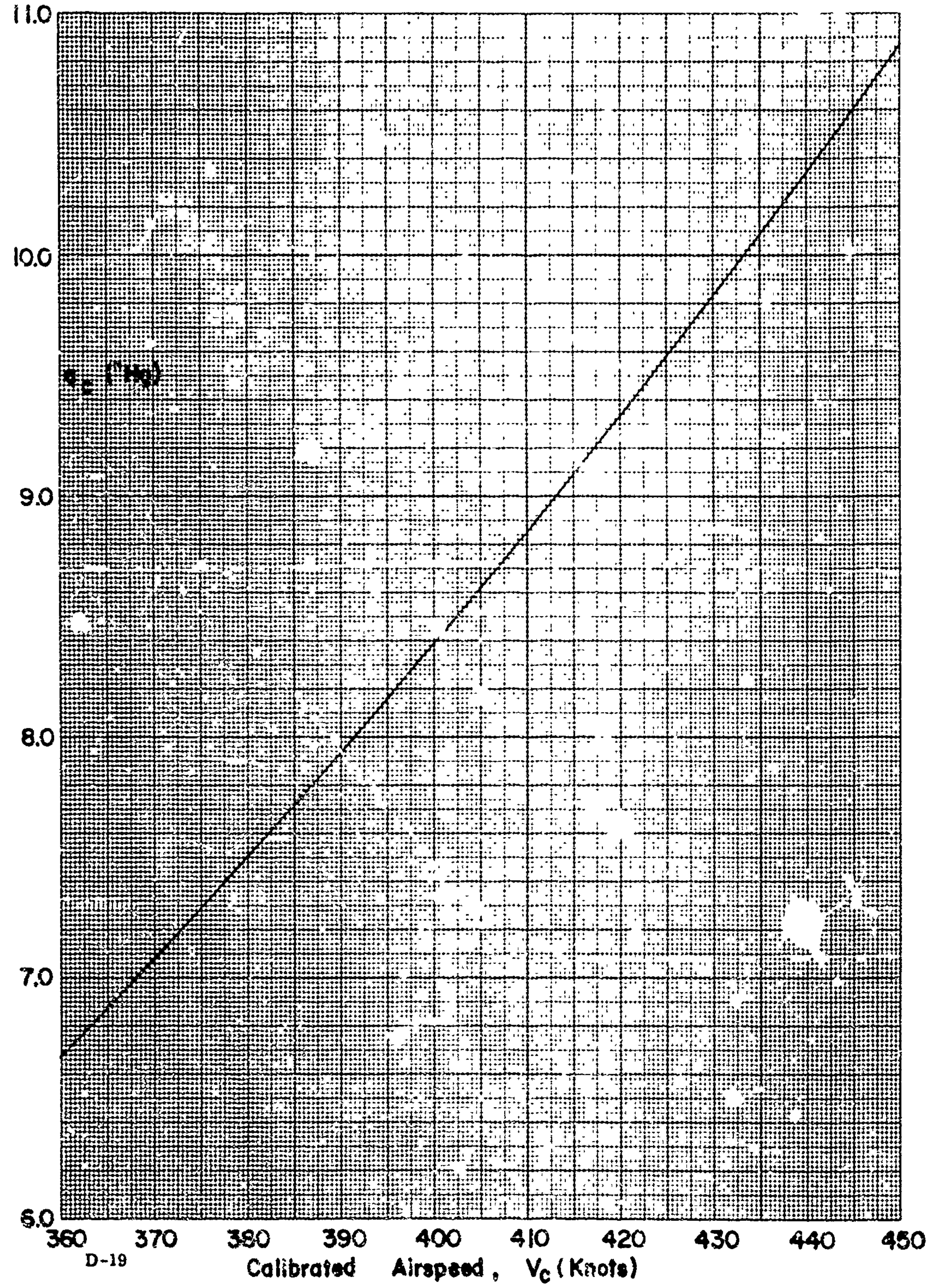


Chart D-3, Continued

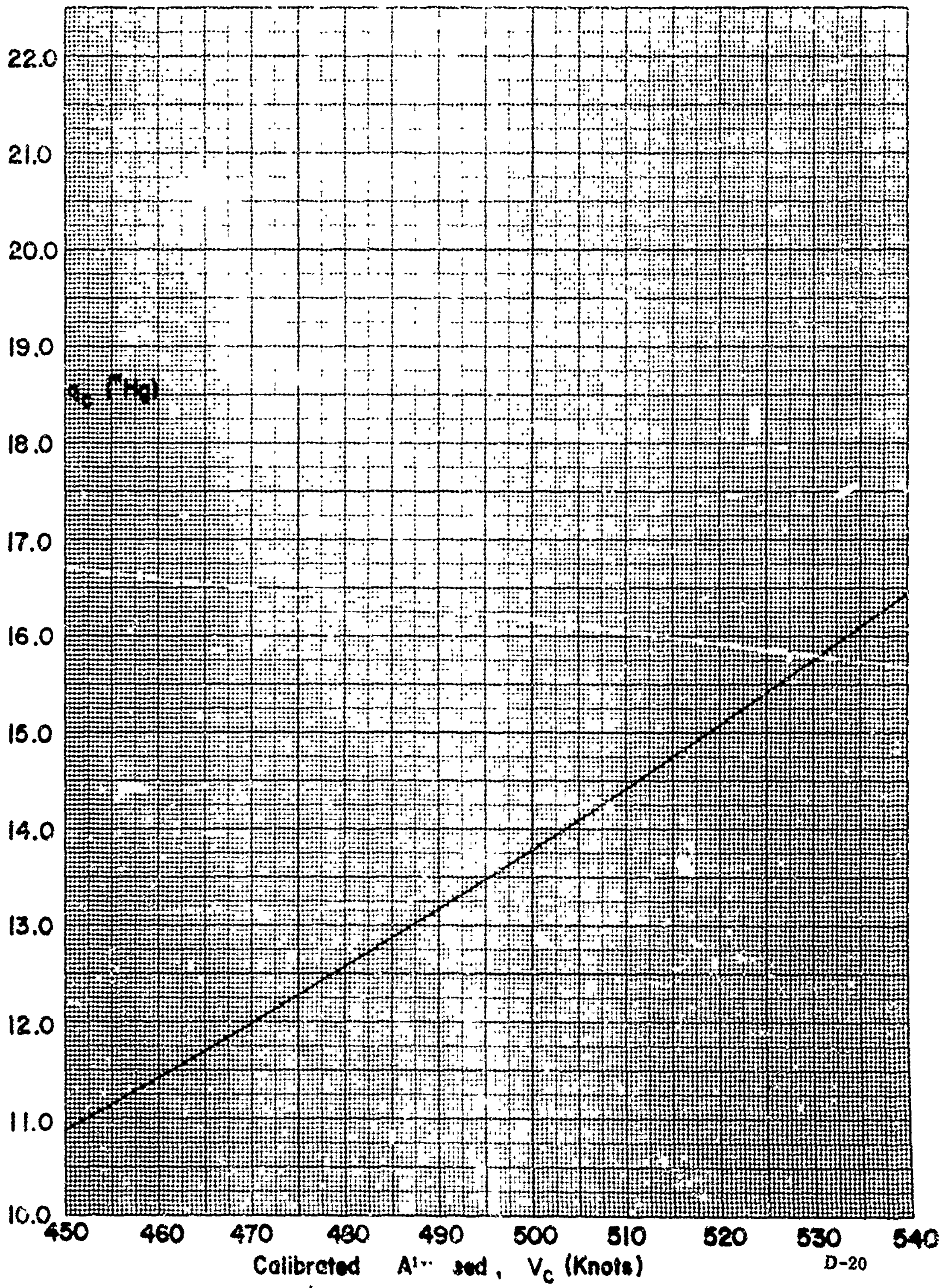


Chart D-3, Continued

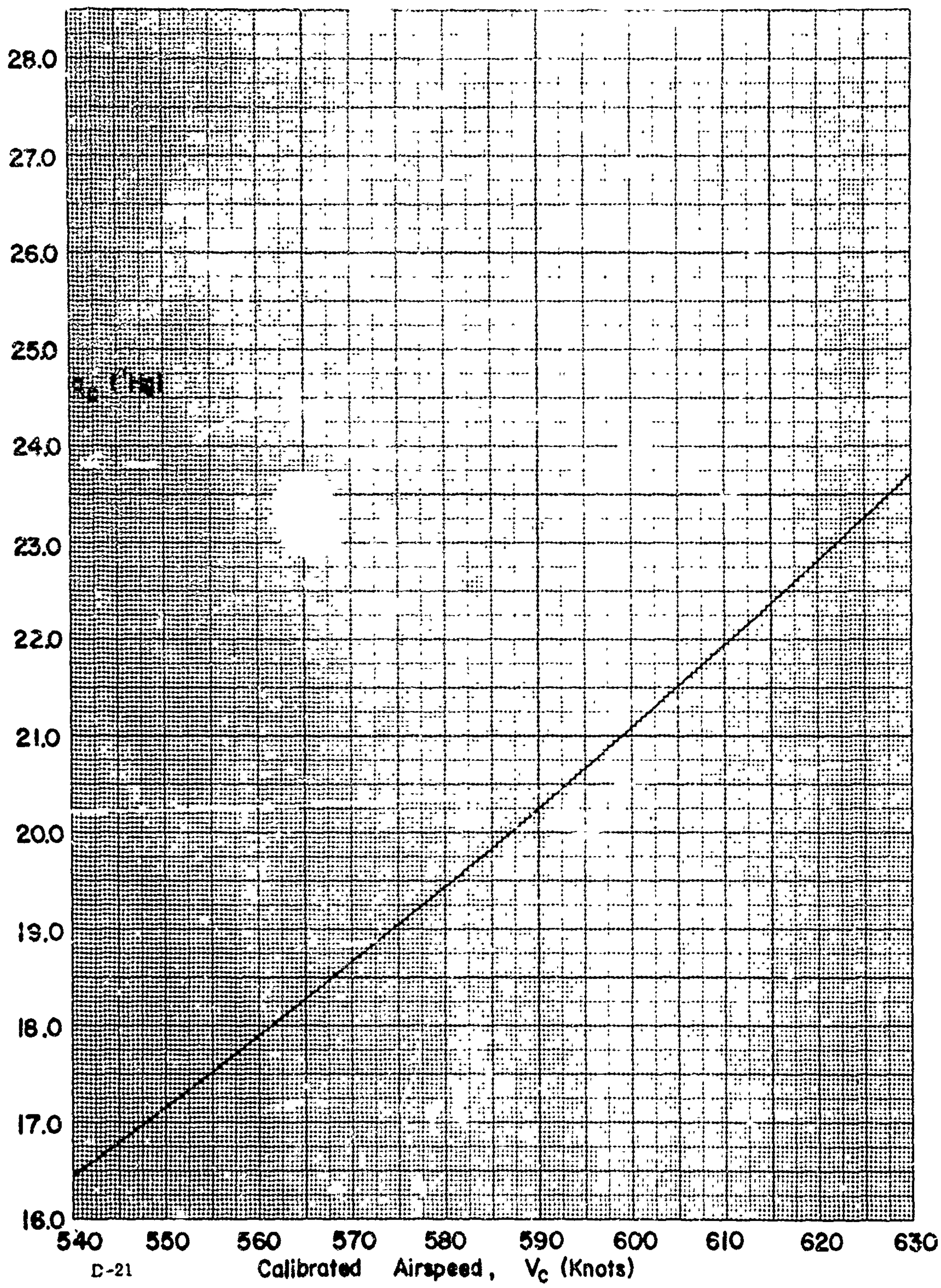


Chart D . Continued

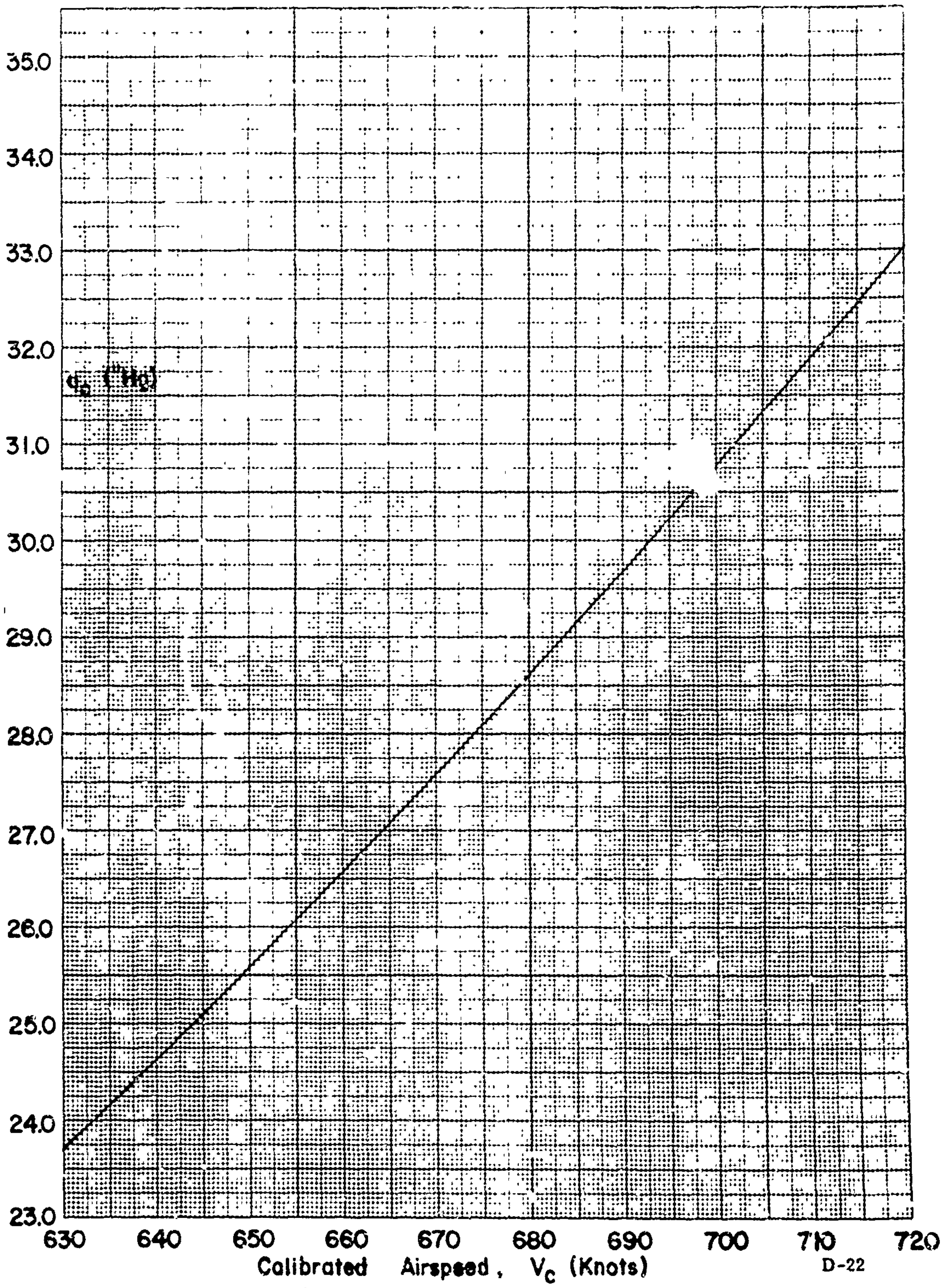


Chart D-3, Continued

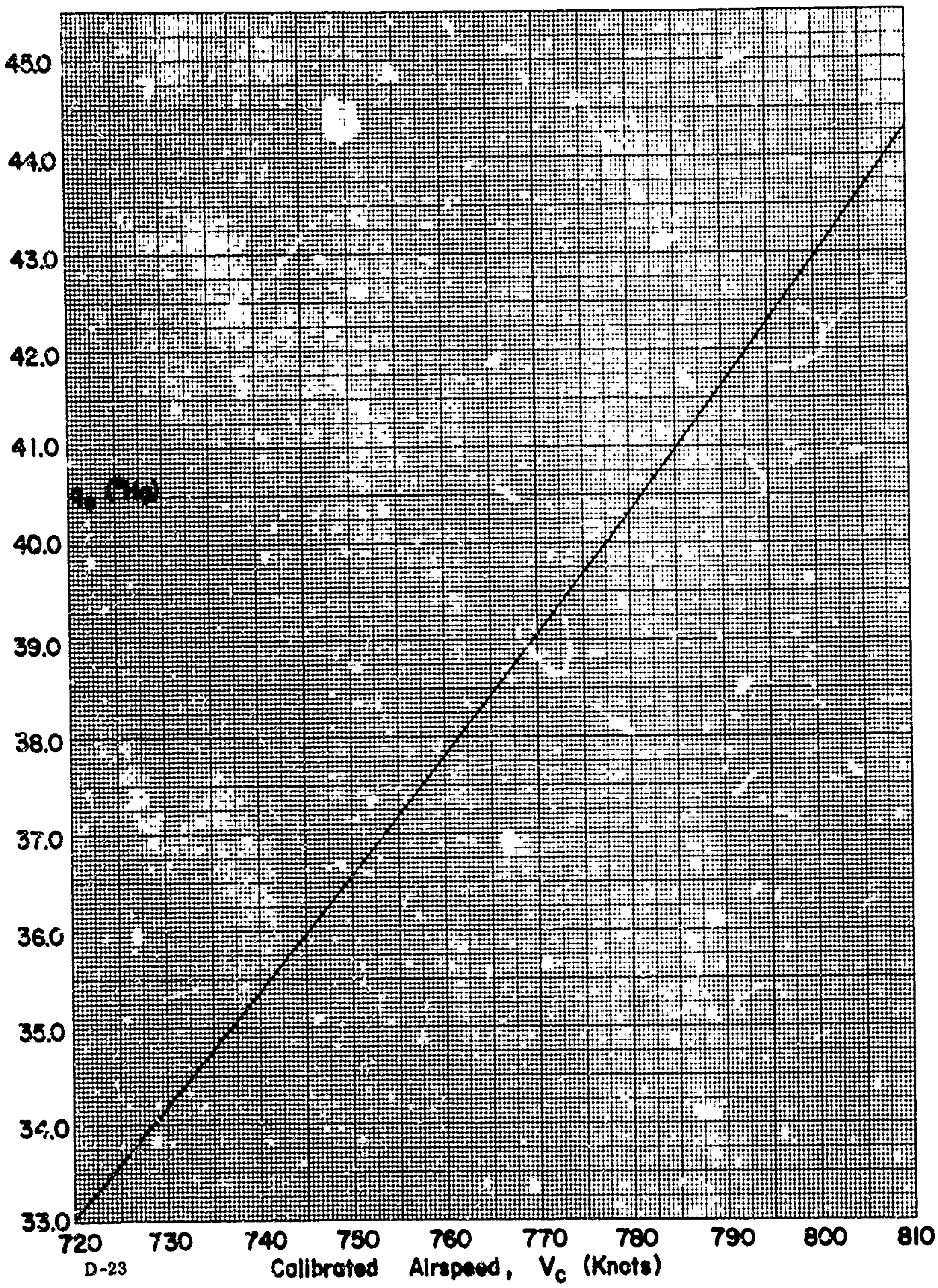


Chart D-3, Continued

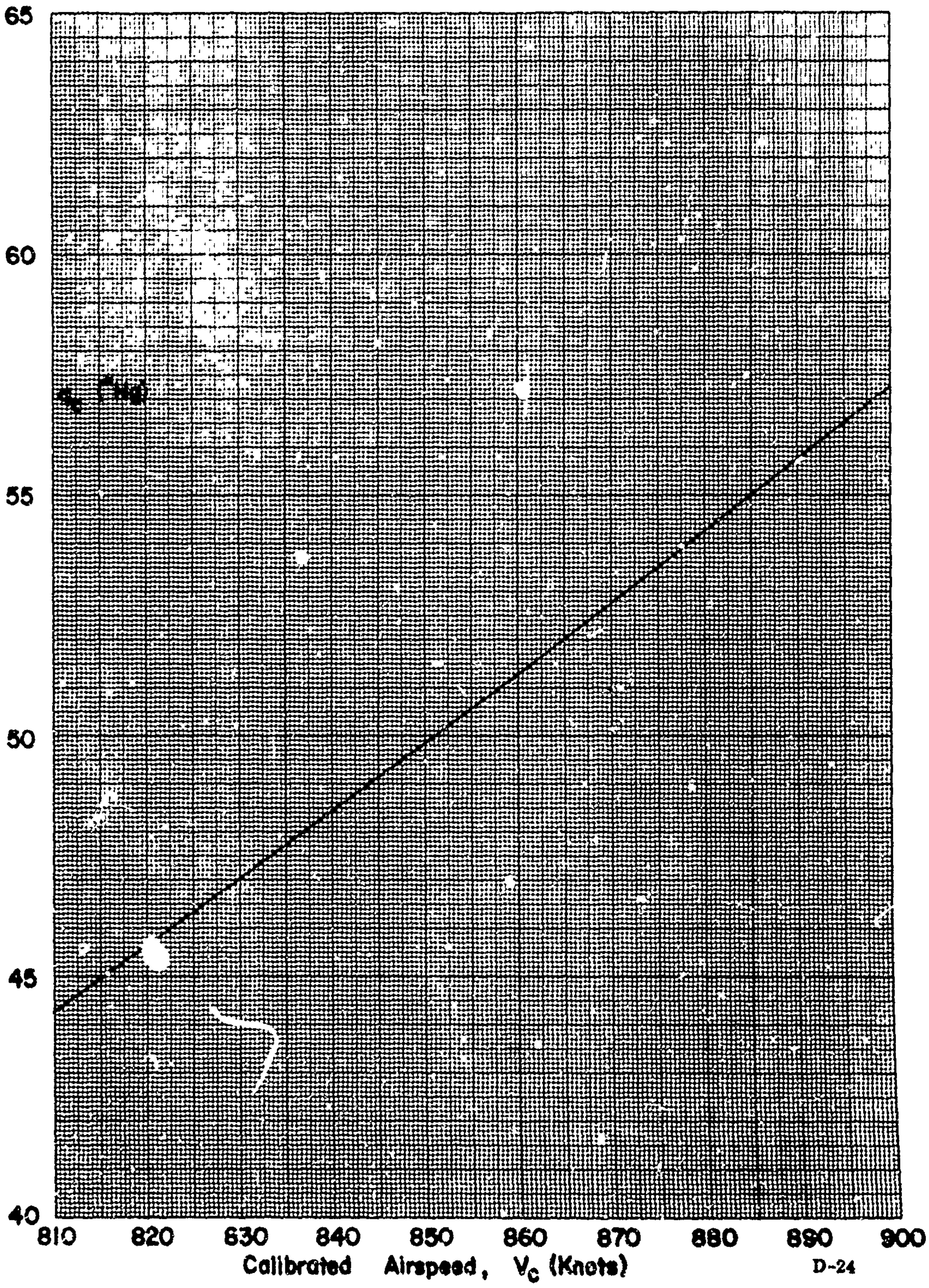
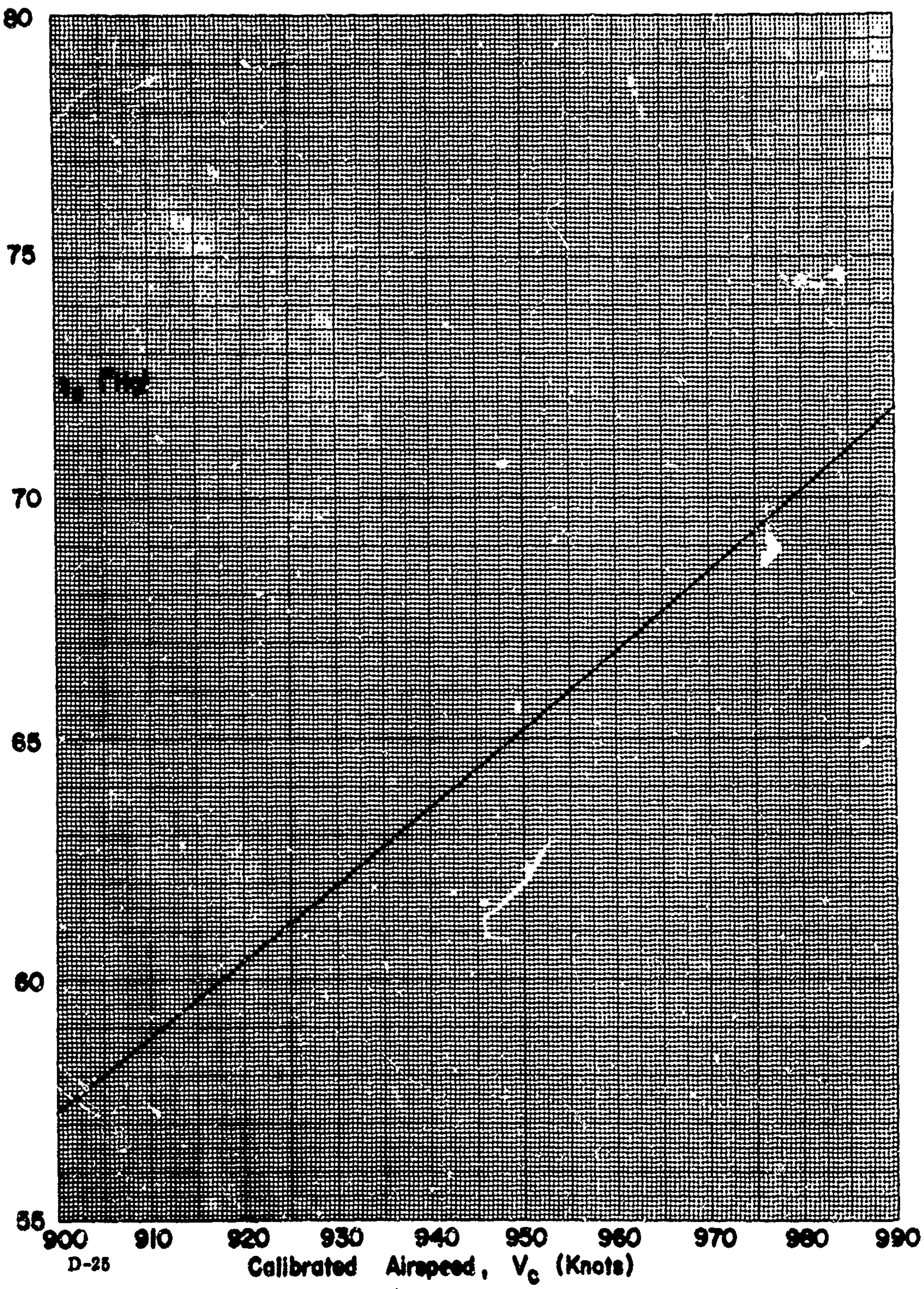


Chart D-3, Concluded



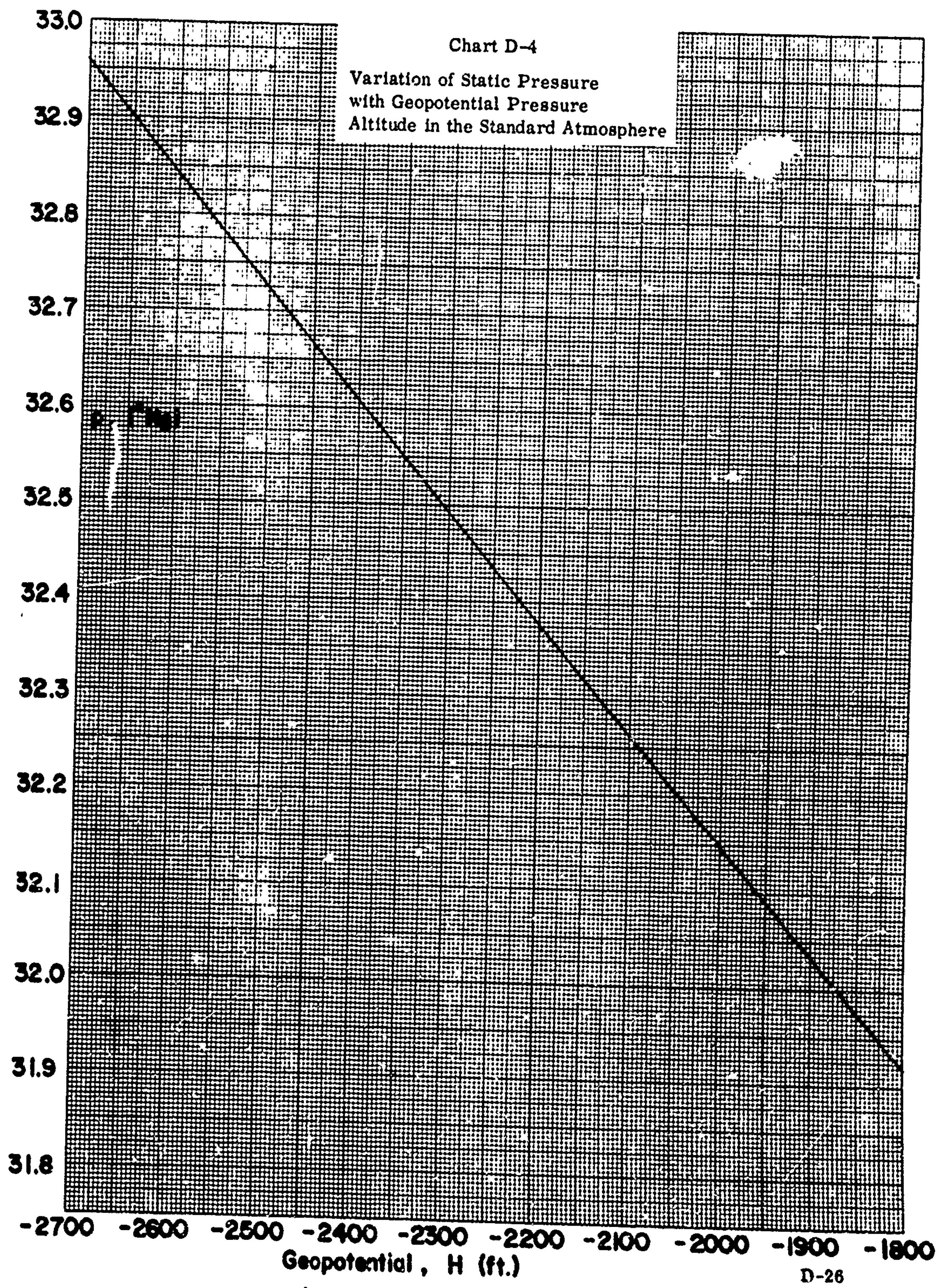


Chart D-4
Variation of Static Pressure
with Geopotential Pressure
Altitude in the Standard Atmosphere
33.0
32.9
32.8
32.7
32.6
32.5
32.4
32.3
32.2
32.1
32.0
31.9
31.8
p, ("Hg)
-2700
-2600
-2500
-2400
-2300
-2200
-2100
-2000
-1900
-1800
Geopotential, H (ft.)

Chart D-4, Continued

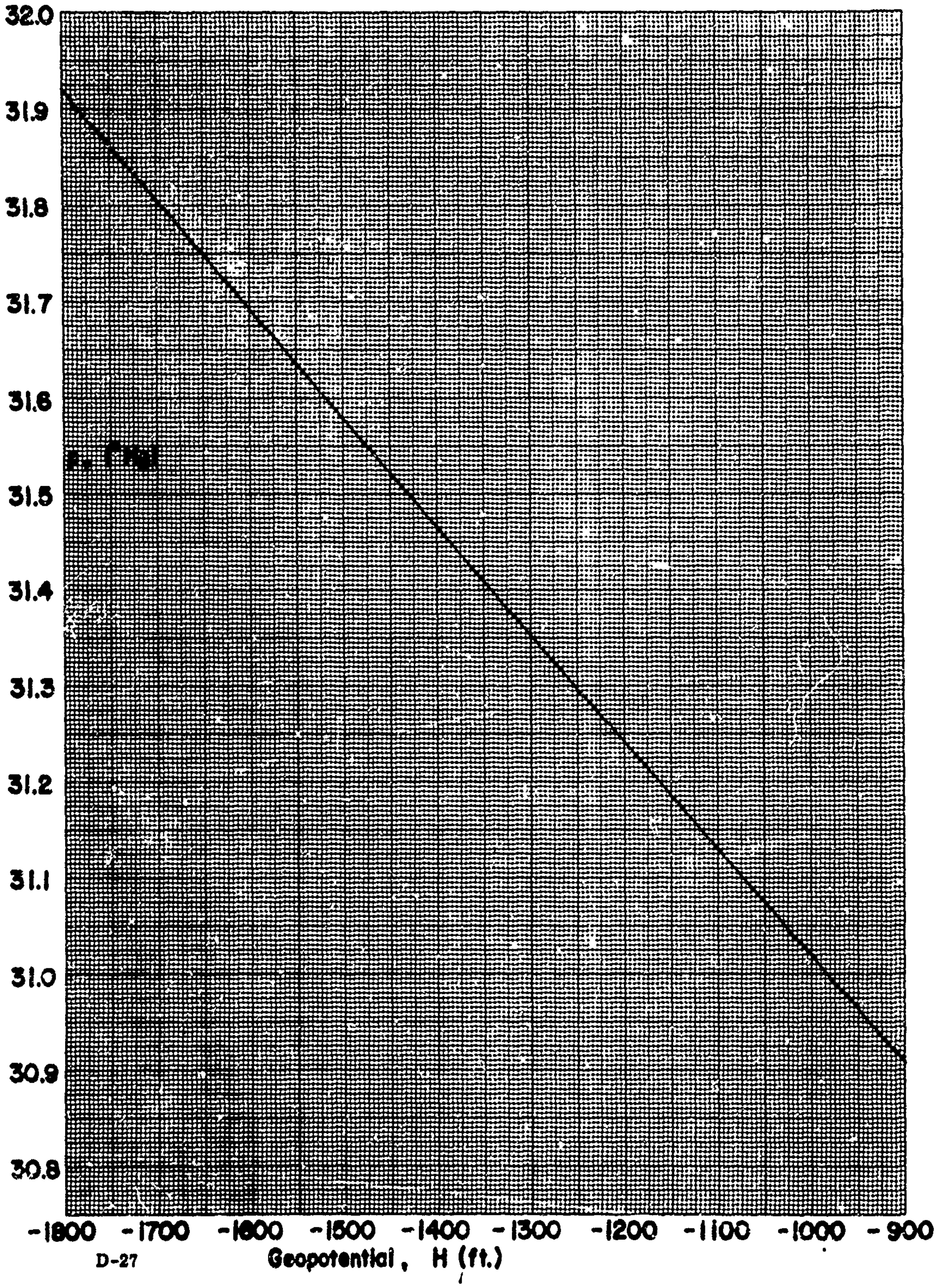


Chart D-4, Continued

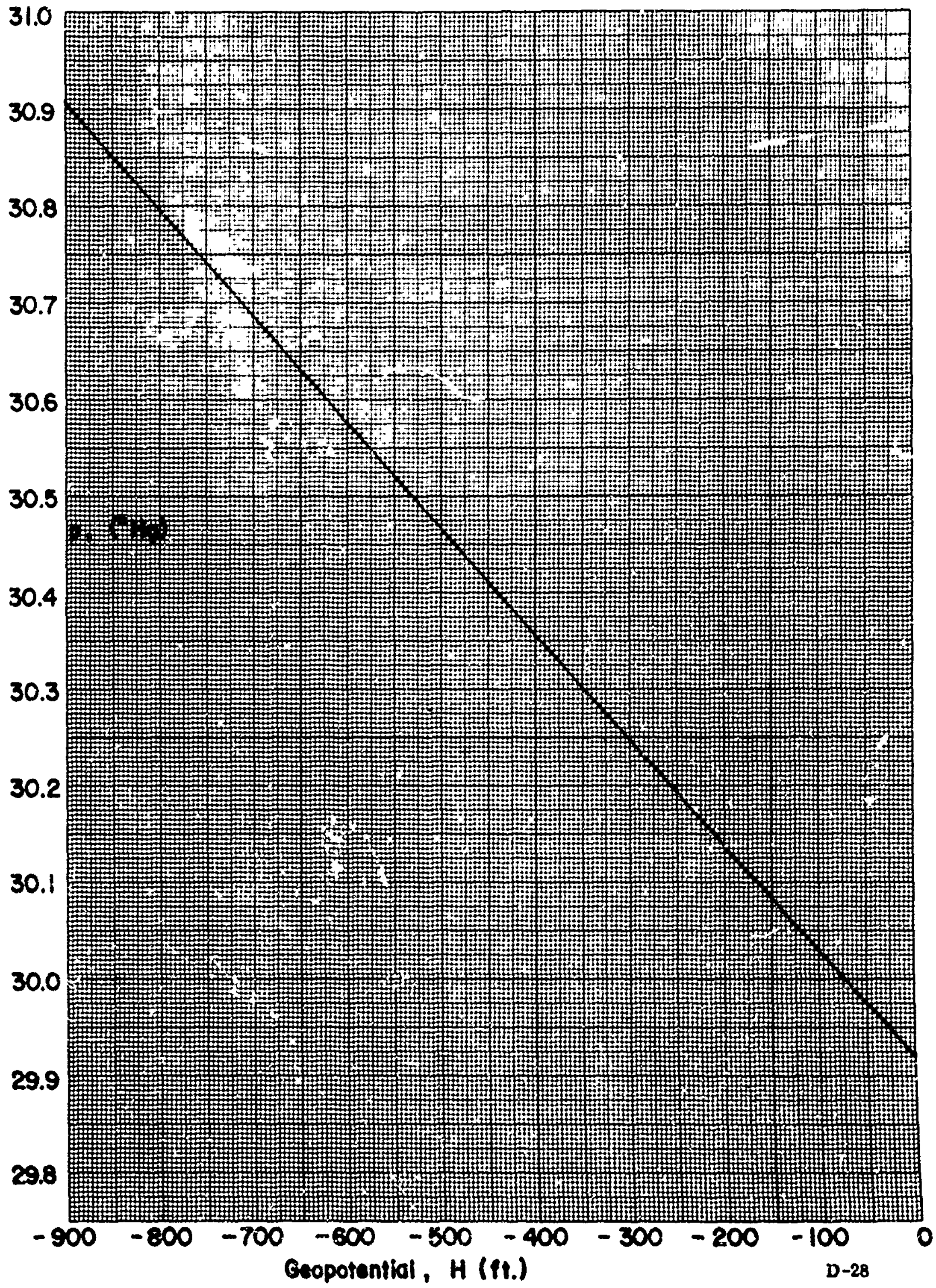


Chart D-4, Continued

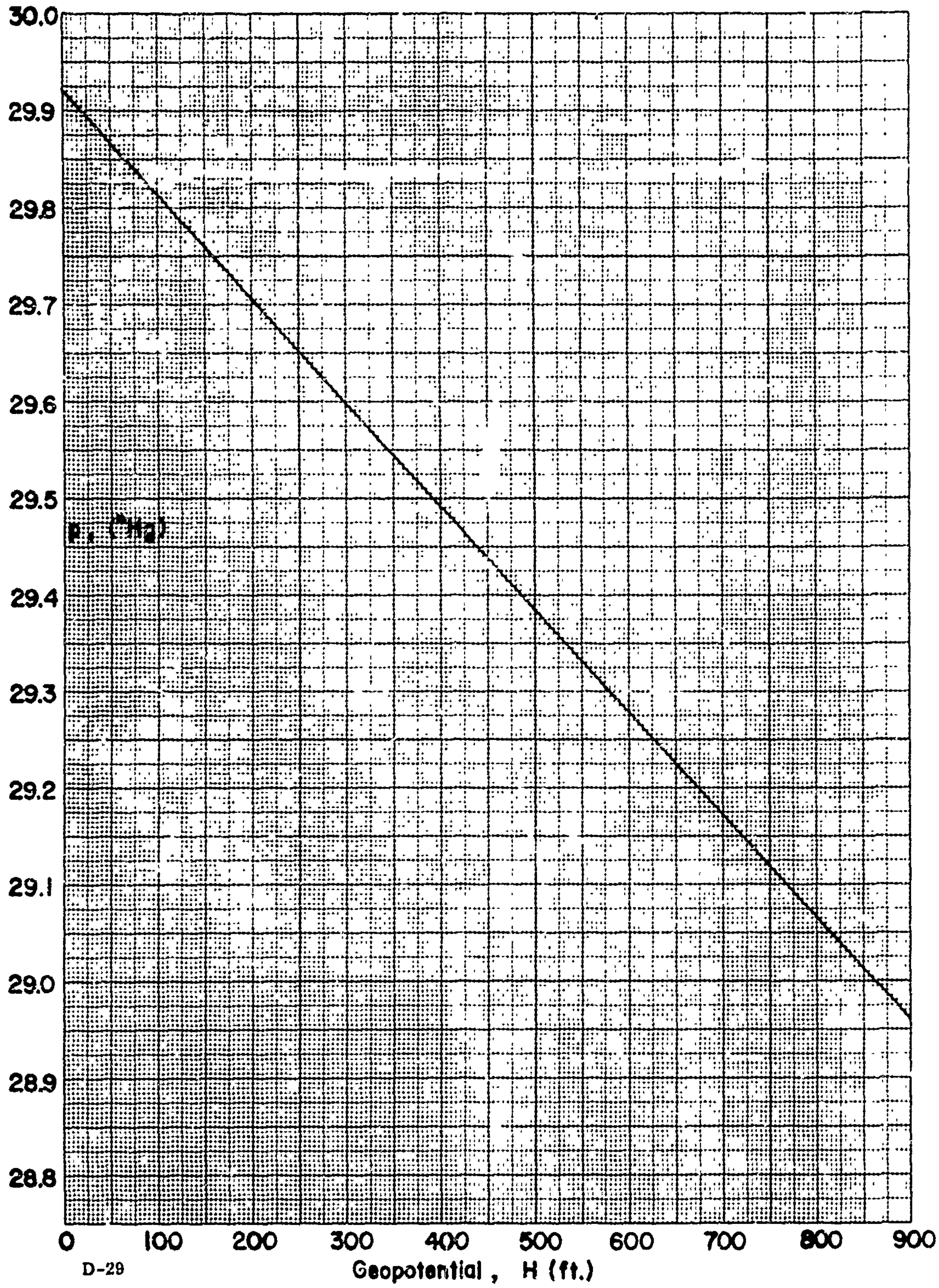


Chart D-4, Continued

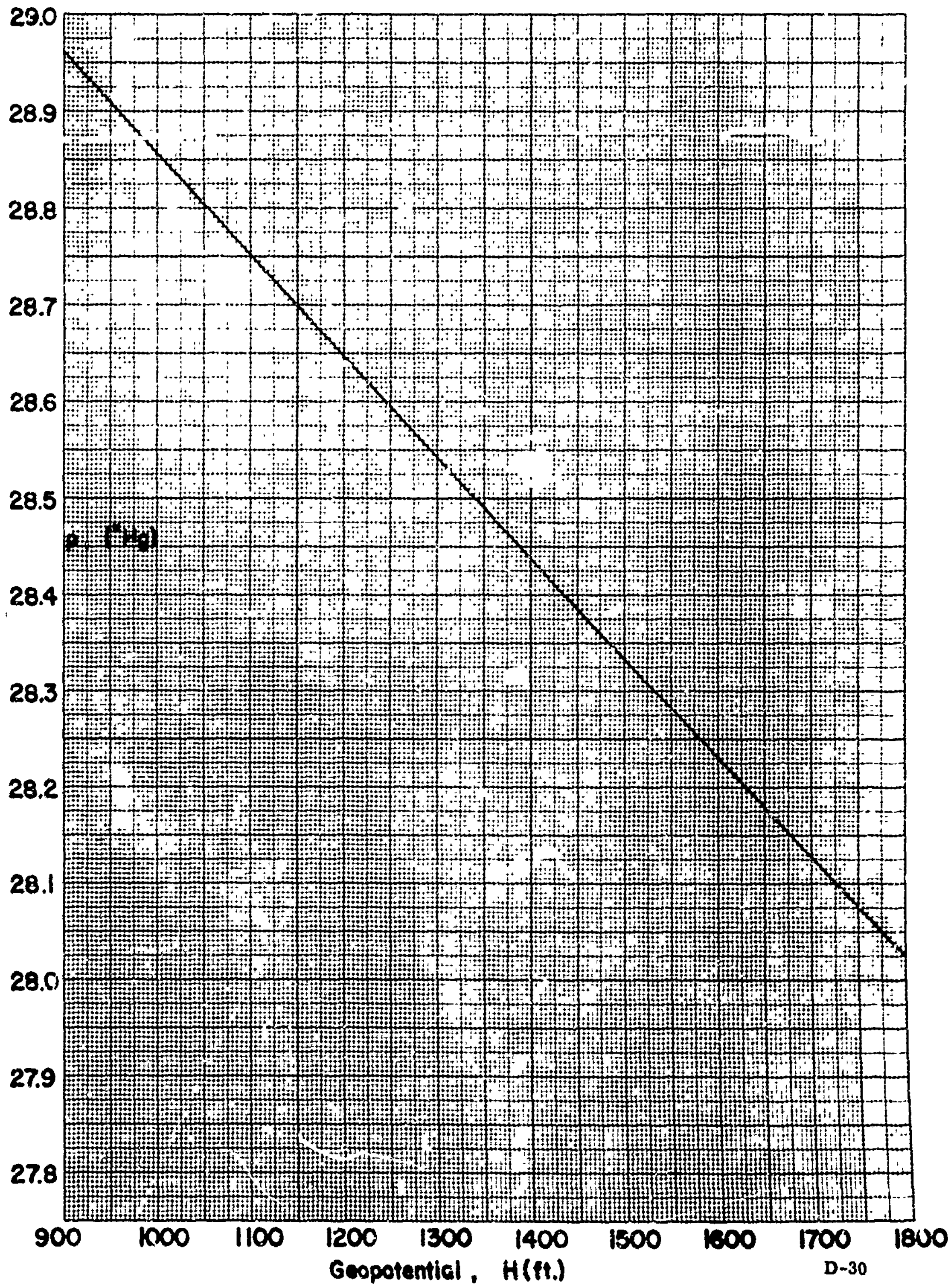


Chart D-4, Continued

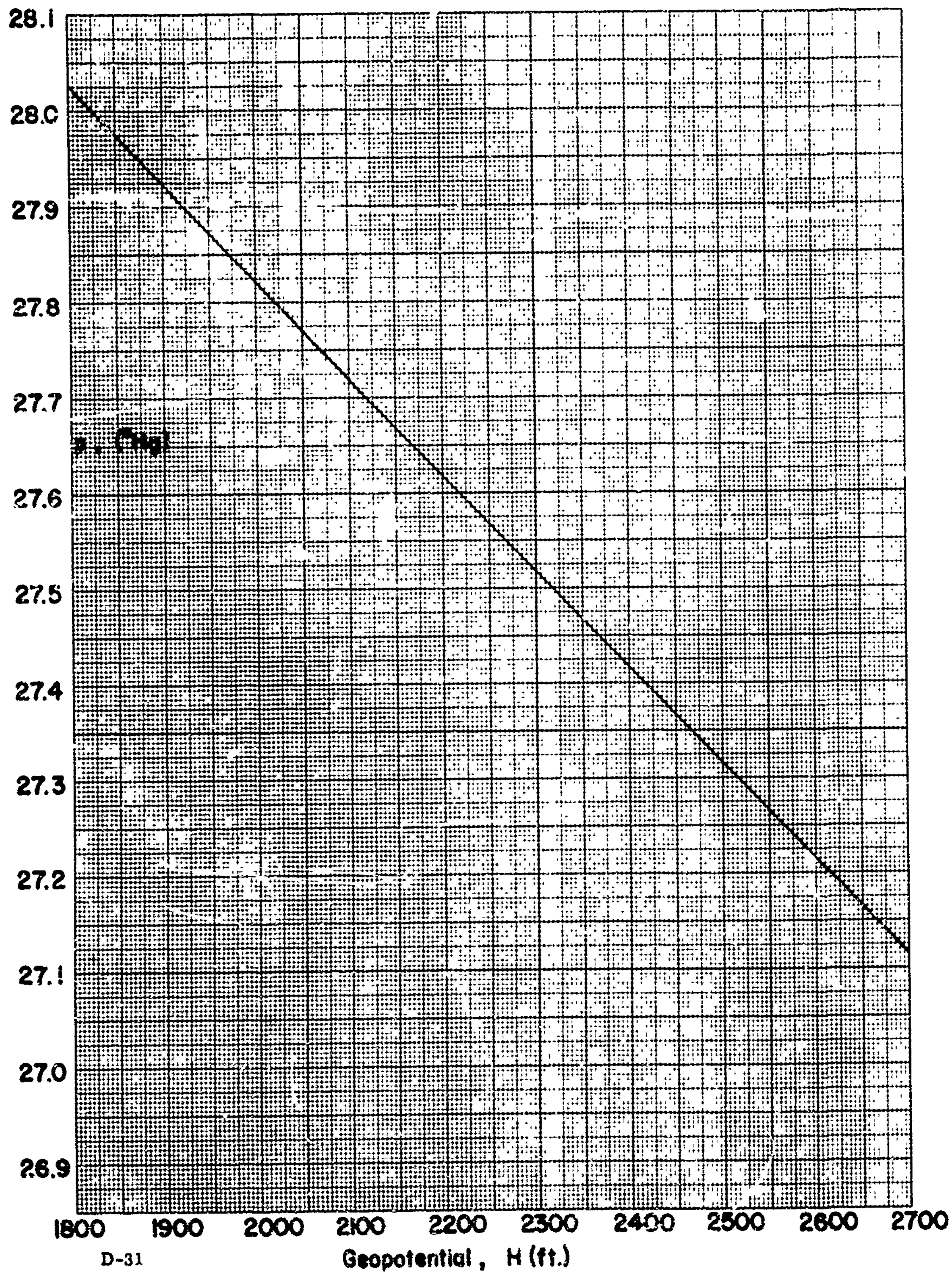


Chart D-4, Continued

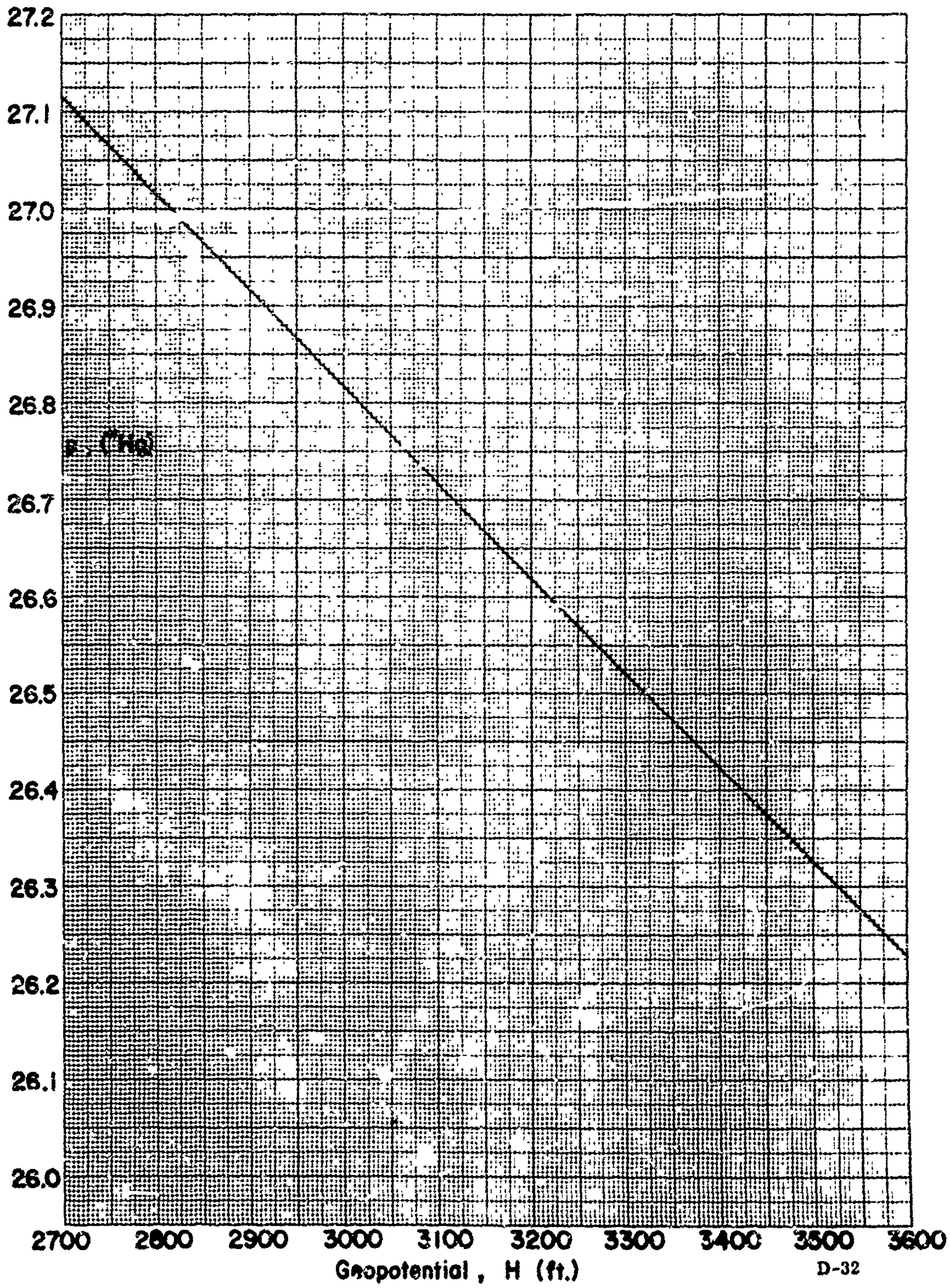


Chart D-4, Concluded

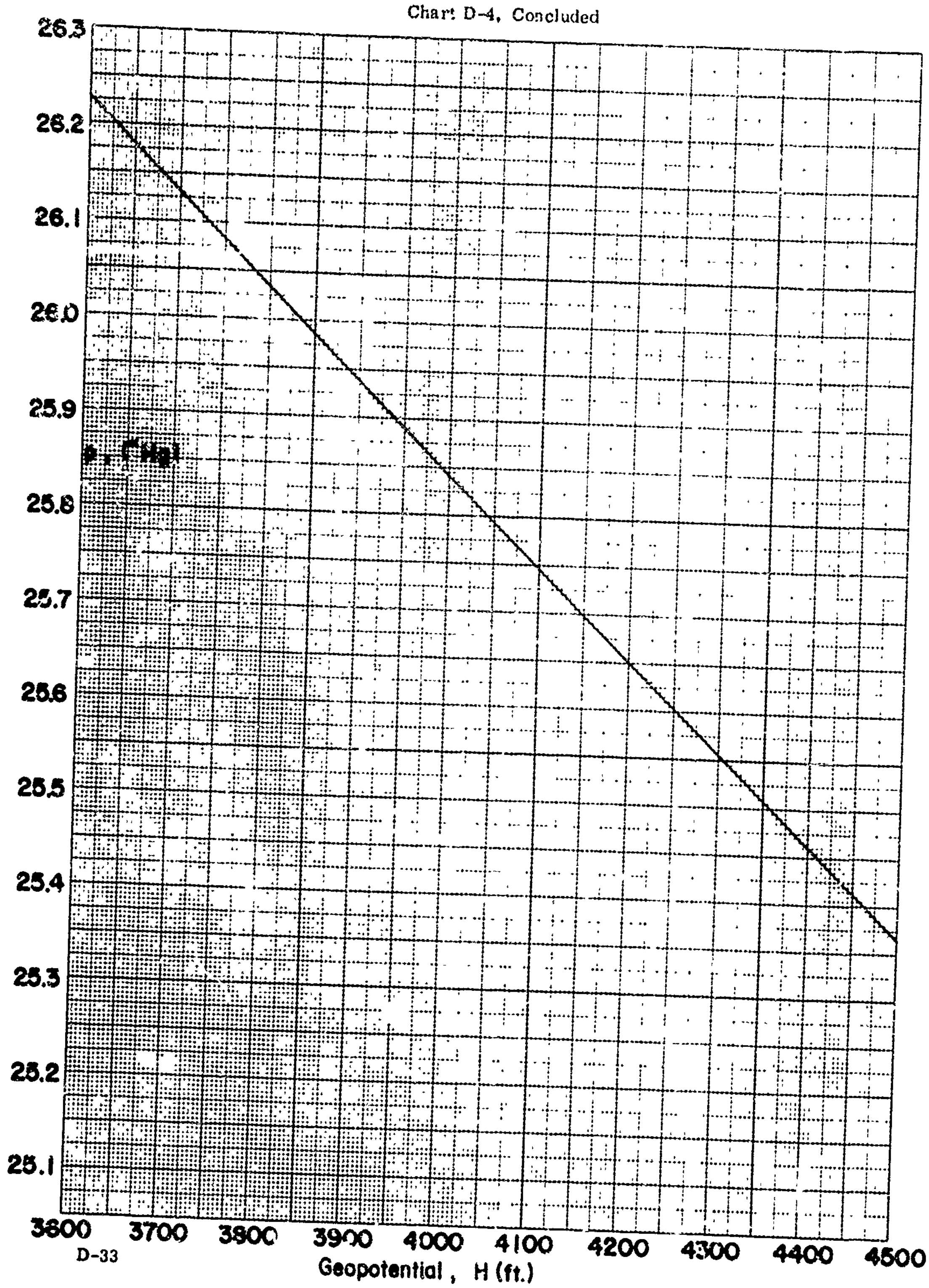


Chart D-5

A[illegible]ed Correction (ΔV_c) as a Function of Static Pressure Position Error (Δp) for [illegible] of Constant Measured Airspeed (V_m).

Chart D-5

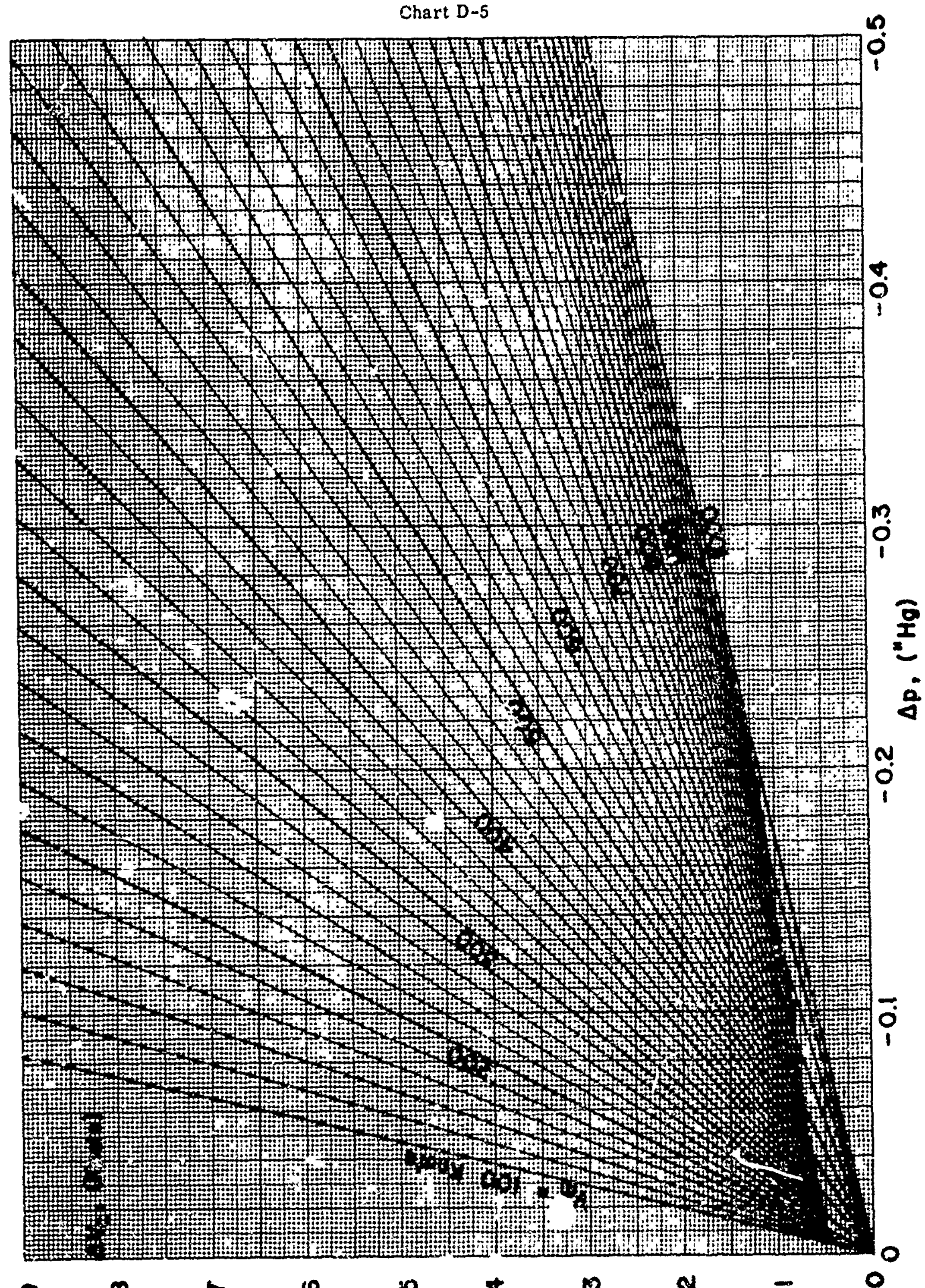


Chart D-5, Continued

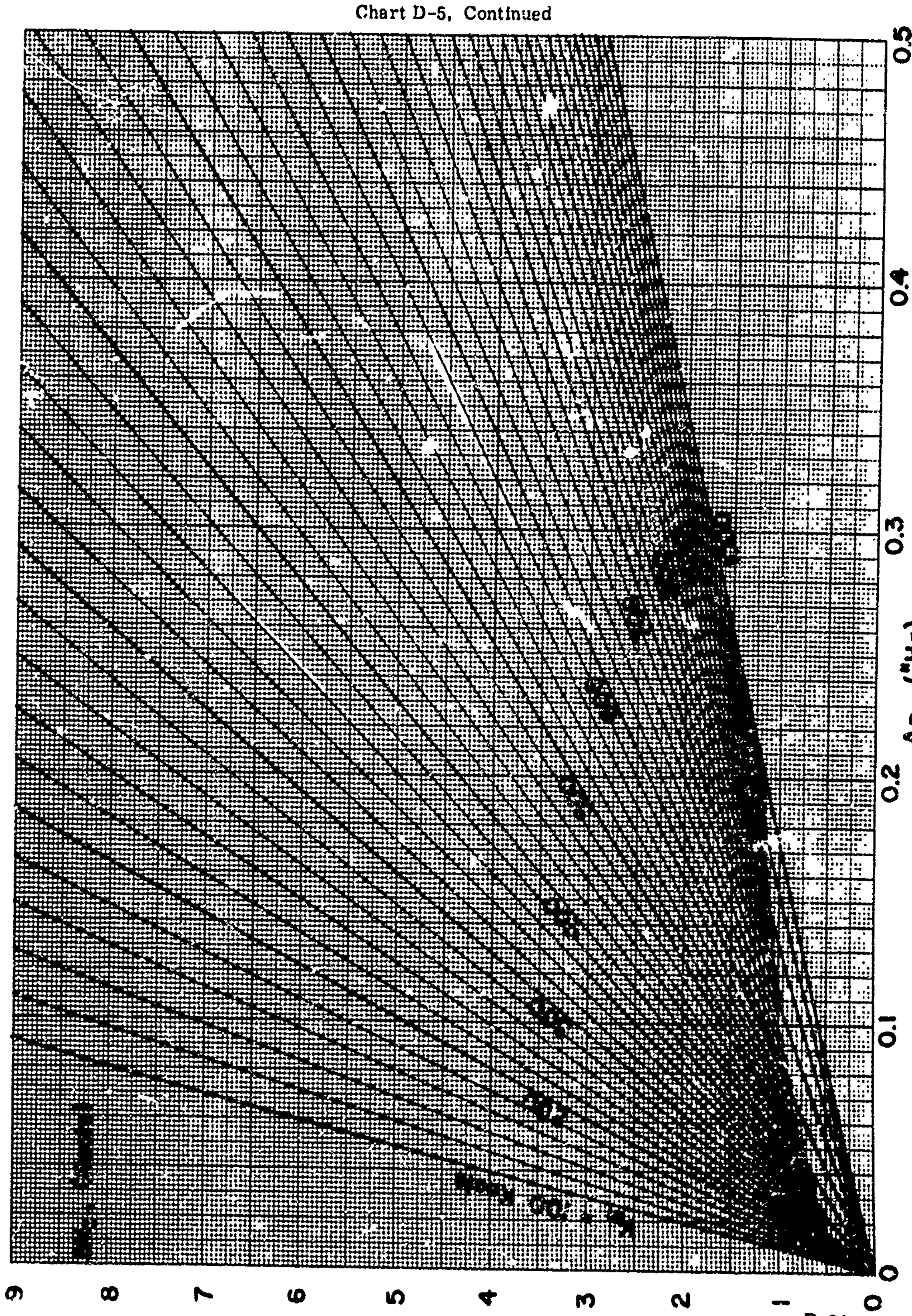


Chart D-5, Continued

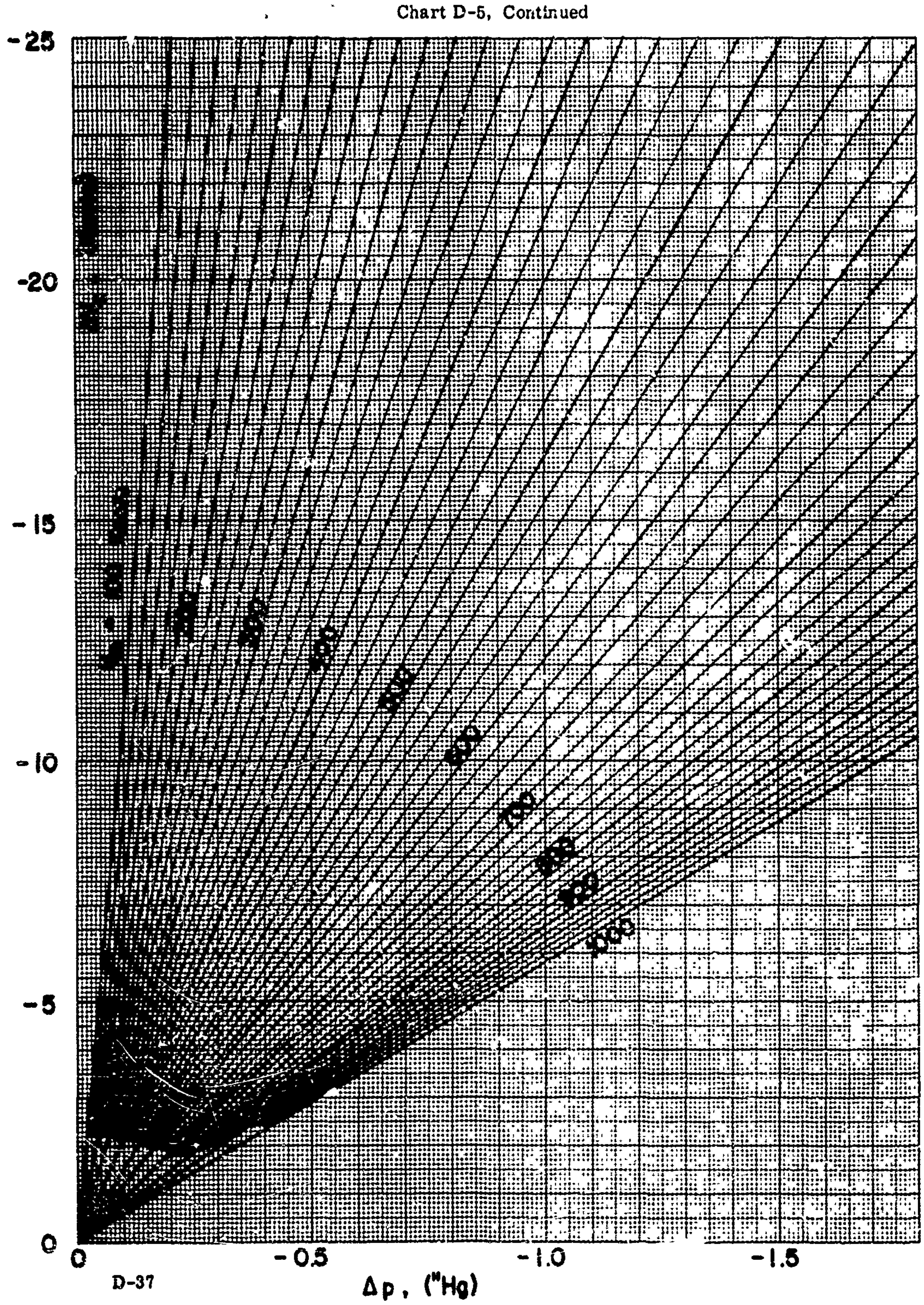


Chart D-5, Continued

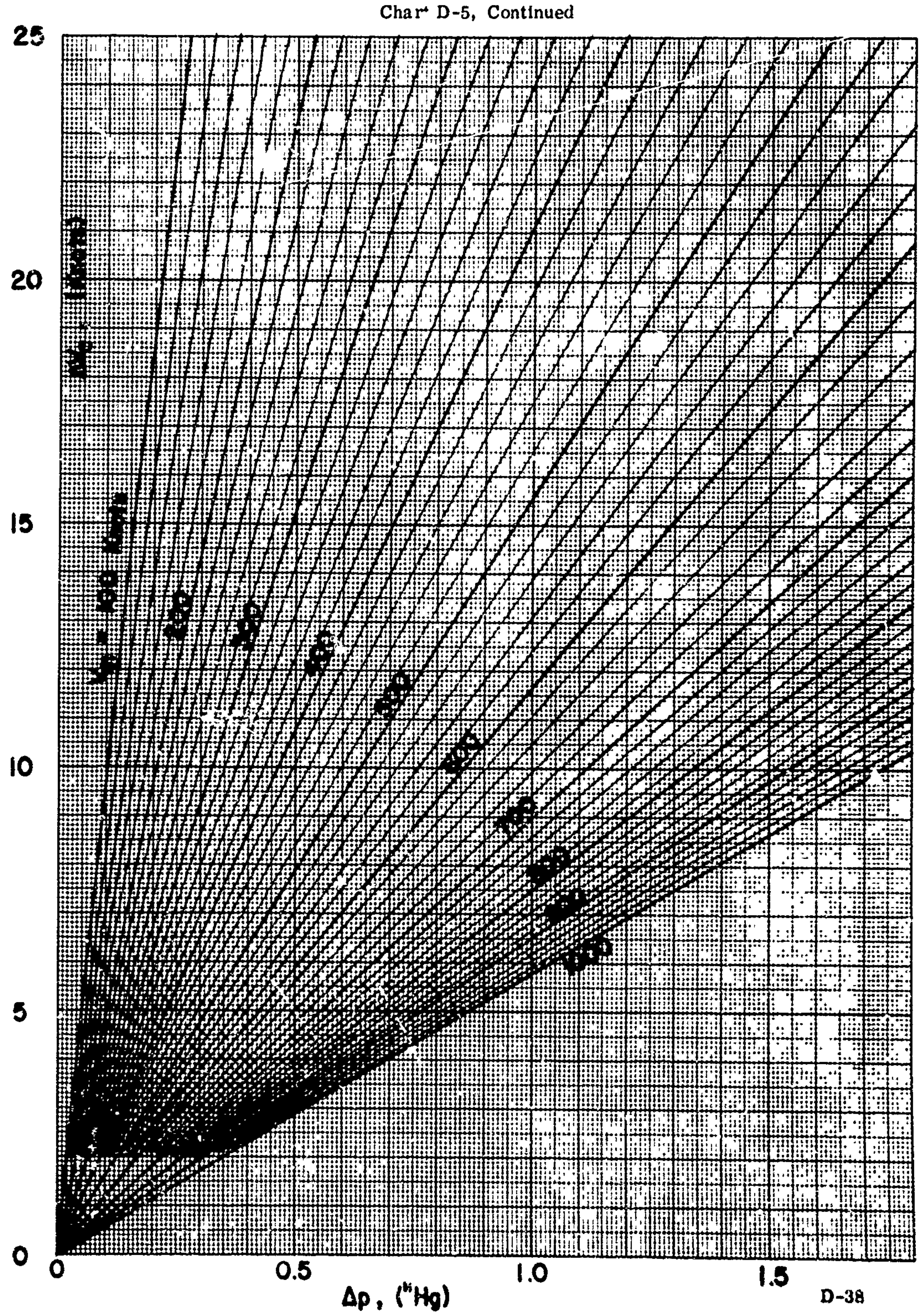


Chart D-5, Continued

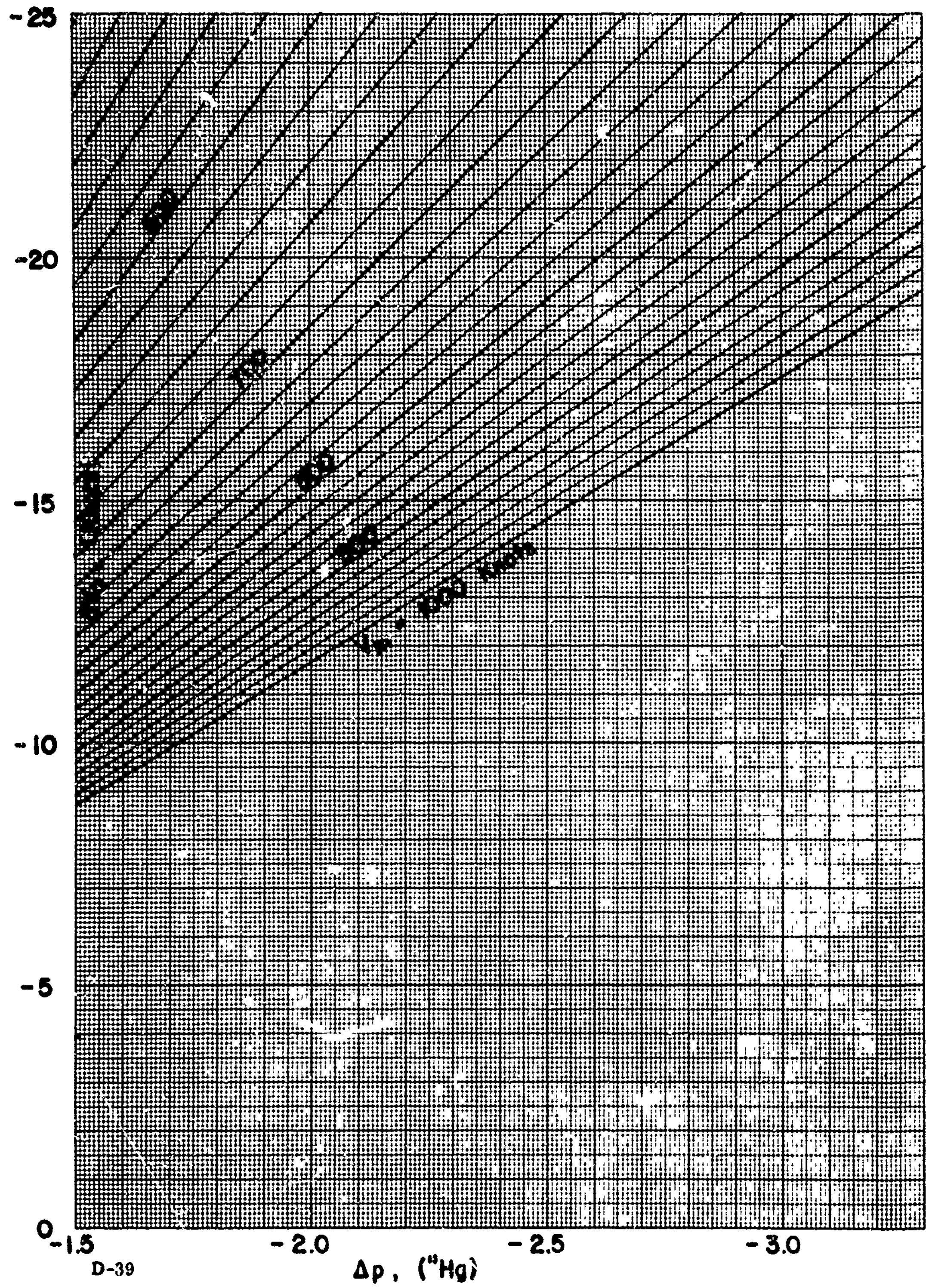


Chart D-5, Concluded